APPENDIX F. SUPPORTING DATA FOR FISH AND CRAB PARAMETERIZATION

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1 Introduction

This appendix summarizes the Lower Passaic River Study Area (LPRSA) analytical data available for blue crab and the selected fish species modeled in the LPRSA bioaccumulation model. Also included is additional detail regarding the justification for the selection of empirical data used to calibrate the bioaccumulation model.

2 Overview of LPRSA Fish Sample Compositing and Analysis

LPRSA fish tissue samples were collected during 2009 and 2010 sampling events (Windward 2010a, [in prep]-c).

In August and September 2009, a large number of blue crab and fish representing numerous fish species were collected from the LPRSA (Windward 2010a). The compositing plan for crab and fish collected in 2009 was agreed upon by the Cooperating Parties Group (CPG) and US Environmental Protection Agency (USEPA) during multiple meetings from January through June of 2010, as documented in multiple memoranda and tables, as follows:

- The *Revised Sample Analysis Plan for Blue Crab Tissue for the Lower Passaic River Restoration Project* memorandum (Windward 2010b) (approved by USEPA on February 8, 2010)
- The *Revised Sample Analysis Plan for Catfish/Bullhead, Carp, Bass, White Sucker, and Northern Pike Tissue for the Lower Passaic River Restoration Project (Revised Fish Sample Analysis Plan, Part 1)* memorandum (Windward 2010e) (approved by USEPA on May 21, 2010)
- The final white perch and American eel analytical plan tables (Windward 2010c, d) (approved by USEPA on June 15, 2010)

In response to USEPA's comments (Vaughn 2010) on the CPG's November 6, 2009, proposed fish analysis plan (Windward 2009a), fish collected in 2009 were analyzed as individuals, rather than composites, when possible (i.e., when the fish collected were large enough for analysis as individual fish). Individual fish analyzed as whole-body samples had to weigh a minimum of approximately 150 g to meet analytical mass requirements, and individual fish analyzed as fillet samples had to weigh a minimum of approximately 450 g[1] to meet analytical mass requirements. Consequently, a mix of individual and composite fish samples were analyzed, depending on the size of fish collected. In addition, the whole-body fish dataset included samples analyzed as whole-body samples, as well as samples that were mathematically reconstituted using fillet and carcass weights and concentrations (i.e., reconstituted whole-body samples). For blue crab, whole-body samples were mathematically reconstituted using muscle/hepatopancreas and carcass weights and concentrations (i.e., reconstituted

[1] An individual fish weight greater than 450 g was selected based on the assumption that fish fillet mass makes up one-third (33.3%) of whole-body fish mass. A whole-body sample mass of 450 g is therefore needed to achieve an estimated fillet mass that meets minimum mass requirements (i.e., 150 g).

whole-body samples).

Between June and August 2010, small forage fish were collected from the LPRSA. Small forage fish specimens were composited according to a USEPA-approved compositing memorandum:

- The *Revised Analysis Plan for the Small Forage Fish Tissue Samples* (Windward 2010f) (approved by USEPA during the teleconference calls on August 5, 2010, and finalized per USEPA comments received October 25 and 26, 2010)

Table 2-1 summarizes the fish and blue crab samples analyzed from the LPRSA based on 2009 and 2010 sampling.

Table 2-1. Summary of LPRSA fish and blue crab samples

Fish Species	Sample Type	Tissue Type			
		Fillet	Carcass	Whole Body (reconstituted)	Whole Body
Gizzard shad[a]	composite	0	0	0	3
Mummichog	composite	0	0	0	18
Other small forage fish[b]	composite	0	0	0	9
Blue crab	composite	0	24	24[c]	0
Carp	individual	12	0	0	12
Brown bullhead[a]	individual	0	0	0	6
Channel catfish	individual	11	11	11	0
White catfish	individual	19	19	19	0
White sucker[a]	individual	5	5	5	0
White perch	individual	2	1	1	4
	composite	17	-	-	15
	Total	**19**	**1**	**1**	**19**
American eel	individual	17	1	1	12
	composite	15	1	1	7
	Total	**32**	**2**	**2**	**19**
Largemouth bass	individual	2	2	2	0
	composite	1	1	1	0
	Total	**3**	**3**	**3**	**-**
Smallmouth bass	composite	3	3	3	0
Northern pike[a]	individual	1	1	1	0

[a] These species were not modeled explicitly in the bioaccumulation model, but these data were considered as part of the uncertainty assessment.

[b] Includes the following small forage fish samples: white perch (n = 2 samples), pumpkinseed (n = 1), silver shiner (n = 1), spottail shiner (n = 1), and mixed forage fish (n = 4). Gizzard shad were also analyzed but were not included as small forage fish samples in the bioaccumulation model, since gizzard shad are more representative of filter-feeding fish, which were modeled as a separate compartment in the bioaccumulation model.

[c] Reconstituted whole-body tissue concentrations for blue crab were calculated using muscle/hepatopancreas

and corresponding carcass concentrations.
LPRSA – Lower Passaic River Study Area

3 Fish and Crab Data Used to Calibrate the Bioaccumulation Model

This section describes the data used to calibrate the bioaccumulation model for blue crab and each of the selected fish compartments. Tables 3-1 and 3-2 summarize the available whole-body data that were used to calibrate the bioaccumulation model. Figures in the following subsections are presented for 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and total polychlorinated biphenyl (PCB) congeners. Tetrachlorobiphenyl concentration patterns were found to be similar to that of total PCB congeners (Appendix J).

Table 3-1. Summary of analytical tissue samples used for model calibration

LPRSA Area	Number of Whole-Body Samples											
	Blue crab		Common Carp		White Perch		Catfish[a]		American Eel		Bass[b]	
	C	I	C	I	C	I	C	I	C	I	C	I
RM 0 – RM 2 (Reach 1)	8	-	-	-	-	2	-	-	1	1	-	-
RM 2 – RM 4 (Reach 2)	6	-	-	-	-	1	-	0[c]	1	-	-	-
RM 4 – RM 6 (Reach 3)	4	-	-	0[d]	6	-	-	4	-	3	-	-
RM 6 – RM 8 (Reach 4)	4	-	-	2	2	-	-	1	-	4	1	-
RM 8 – RM 10 (Reach 5)	2	-	-	2	3	-	-	3	1	2	2	1
RM 10 – RM 12 (Reach 6)	-	-	-	2	-	1	-	7	-	2	-	-
RM 12 – RM 14 (Reach 7)	-	-	-	2	1	1	-	4	-	1	-	-
RM 14 – RM 17.4 (Reach 8)	-	-	-	2	3	-	-	10	5	-	1	1
Site-wide total	**24**	**0**	**0**	**10**	**15**	**5**	**0**	**29**	**8**	**13**	**4**	**2**
	24		**10**		**20**		**29**		**21**		**6**	

[a] Includes white catfish and channel catfish.

[b] Includes smallmouth and largemouth bass.

[c] One individual catfish sample was collected between RM 2 and RM 4; however, this sample was excluded from the calibration dataset because it was collected outside of the modeling area identified for catfish (see Section 3.2.4 of the main document).

[d] Two individual carp samples were collected between RM 4 and RM 6; however, these samples were excluded from the calibration dataset because they were collected outside of the modeling area identified for carp (see Section 3.2.4 of the main document).

C – composite fish sample
I – individual fish sample
LPRSA – Lower Passaic River Study Area
RM – river mile

Table 3-2. Summary of empirical fish and crab tissue concentrations for model calibration

Species	Modeling Area	No. of Samples	Concentration[a]

			2,3,7,8-TCDD (ng/kg ww)		Tetrachlorobiphenyl (µg/kg ww)		Total PCB Congeners (µg/kg ww)	
			Mean	SD	Mean	SD	Mean	SD
Blue crab	site-wide[b]	24	51	16	59	14	320	100
Carp	RM 7 - RM 17.4	10[c]	430	420	1,100	620	4,300	2,200
Catfish[d]	RM 4 - RM 17.4	29[e]	130	100	370	250	2,200	1,600
White perch	site-wide	20	130	70	470	250	2,100	1,200
American eel	site-wide	21	18[g]	14[f]	180	110	1,500	1,200
Bass[g]	RM 7 - RM 17.4	6	60	66	280	190	2,400	2,800

[a] Concentrations are based only on detected concentrations (i.e., all samples in the dataset had detected concentrations), except for American eel and 2,3,7,8-TCDD.

[b] Whole-body concentrations in blue crab collected from RM 0 to RM 10 were used to represent site-wide concentrations.

[c] Two carp samples collected between RM 4 and RM 6 were excluded from the calibration dataset because they were collected outside of the modeling area identified for carp.

[d] Includes white catfish and channel catfish.

[e] One catfish sample collected between RM 2 and RM 4 was excluded from the calibration dataset because it was collected outside of the modeling area identified for catfish.

[f] Summary statistics include one non-detected value in Reach 8 (RM 14 to RM 17.4).

[g] Includes smallmouth and largemouth bass.

PCB – polychlorinated biphenyl
RM – river mile
SD – standard deviation
TCDD – tetrachlorodibenzo-*p*-dioxin
ww – wet weight

3.1 BLUE CRAB

Adult blue crab (*Callinectes sapidus)* were included in the bioaccumulation model separately from the small benthic invertebrate compartments. Blue crab whole-body concentrations were estimated based on mathematically reconstituted muscle-hepatopancreas and carcass samples based on crab collected from Reaches 1 through 5 (river mile [RM] 0 to RM 10). Per the fish/decapod quality assurance project plan (QAPP) (Windward 2009b) and blue crab compositing plan (Windward 2010b), no carcass samples were analyzed above RM 10, although 17 muscle/hepatopancreas crab samples were analyzed above RM 10. The blue crab muscle/hepatopancreas samples collected above RM 10 were of similar size as those collected below RM 10 (Figures 3-1 and 3-2).[2]

Figures 3-3 through 3-8 present concentrations of 2,3,7,8-TCDD and total PCBs in blue crab whole-body samples. The whole-body data based on blue crab collected from RM 0 to RM 10 were assumed to be representative of site-wide concentrations (i.e., concentrations in crab from RM 0 to RM 17.4) for the purposes of calibrating the bioaccumulation model. However, muscle-hepatopancreas concentrations (which were available from throughout the LPRSA) were slightly less in Reaches 6 through 8 (i.e.,

[2] Only reconstituted whole-body data were used in the bioaccumulation model calibration. However, for informational purposes, Figures 3-1 and 3-2 also show crab sizes for muscle-hepatopancreas data, and Figures 3-3 and 3-4 show concentrations for muscle-hepatopancreas data.

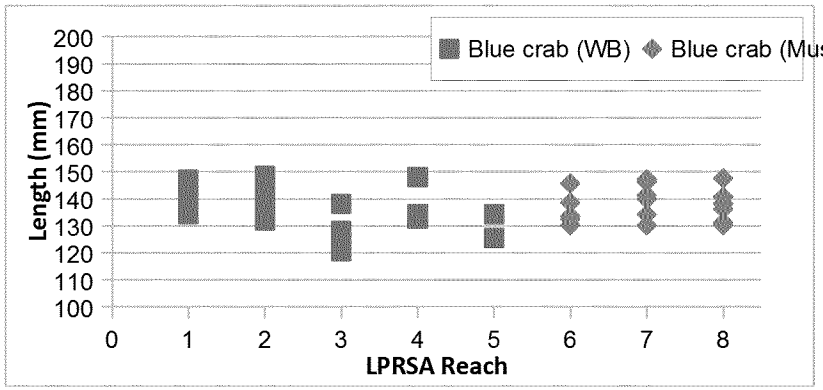
above RM 10) than in Reaches 1 through 5 (i.e., below RM 10). In addition, average concentrations of muscle-hepatopancreas based on data from the entire LPRSA were less than those based on data from Reach 1 through 5 (Table 3-3). Therefore, the site-wide whole-body concentrations used as the basis for calibration for blue crab (i.e., samples collected from Reaches 1 to 5 [below RM 10]) may slightly overestimate concentrations in blue crab collected in the upper freshwater portion of the LPRSA (i.e., between Reaches 6 and 8 [above RM 10]).

Table 3-3. Comparison of LPRSA blue crab combined muscle-hepatopancreas concentrations

LPRSA	Combined Muscle-Hepatopancreas Concentration				
	Count	Total PCBs (µg/kg ww)		2,3,7,8-TCDD (ng/kg ww)	
		Range	Average	Range	Average
RM 0 to RM 10 (Reaches 1 to 5)[a]	24	130 – 790	371	24 – 110	61
RM 10 to RM 17.4 (Reaches 6 to 8)	17	76 – 410	261	4 – 71	33
RM 0 to RM 17.4 (Reaches 1 to 8)	41	76 – 790	326	4 – 110	49

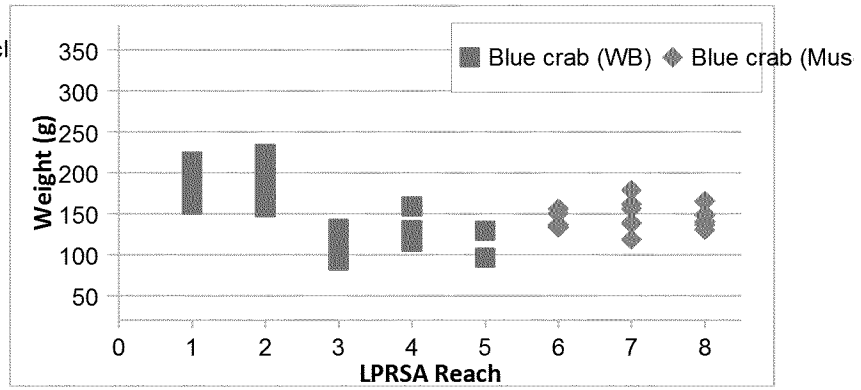
[a] Reconstituted whole-body data based on muscle-hepatopancreas and carcass samples from this LPRSA area (RM 0 to RM 10) were used to calibrate the model for site-wide concentrations. No carcass data were analyzed based on crab collected above RM 10.

LPRSA – Lower Passaic River Study Area
PCB – polychlorinated biphenyl
RM – river mile
TCDD – tetrachlorodibenzo-*p*-dioxin
ww – wet weight



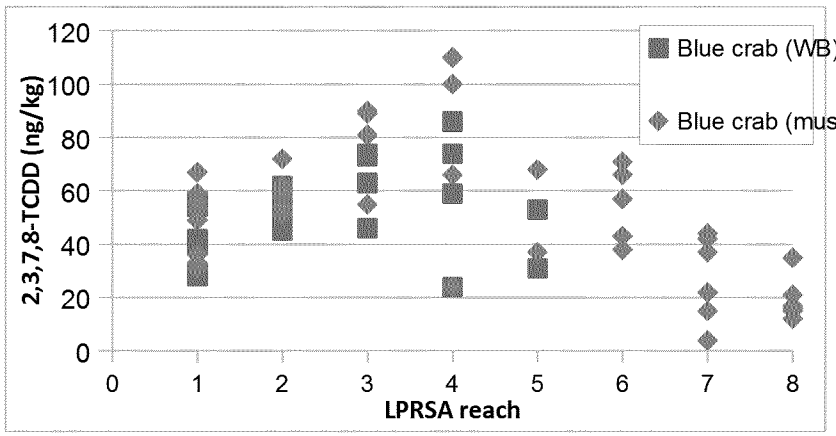
Note: Bars represent minimum and maximum values in composite sample. Muscle+hepatopancreas (HP) data above Reach 5 are shown for informational purposes; only whole-body data were used to calibrate the bioaccumulation model.

Figure 3-1. Mean length of blue crab in analytical composite samples



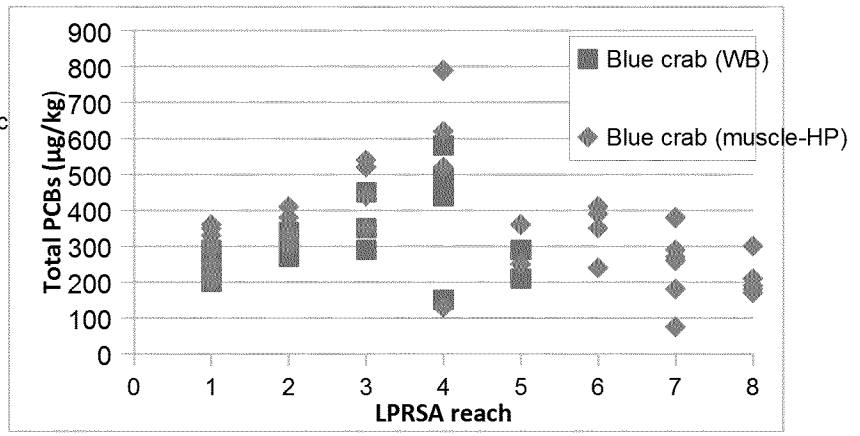
Note: Bars represent minimum and maximum values in composite sample. Muscle+hepatopancreas (HP) data above Reach 5 are shown for informational purposes; only whole-body data were used to calibrate the bioaccumulation model.

Figure 3-2. Mean weight of blue crab in analytical composite samples



Note: Muscle/hepatopancreas (HP) data above Reach 5 are shown for informational purposes; only whole-body data were used to calibrate the bioaccumulation model.

Figure 3-3. Blue crab whole-body 2,3,7,8-TCDD concentrations by LPRSA reach



Note: Muscle/hepatopancreas (HP) data above Reach 5 are shown for informational purposes; only whole-body data were used to calibrate the bioaccumulation model.

Figure 3-4. Blue crab whole-body total PCB concentrations by LPRSA reach

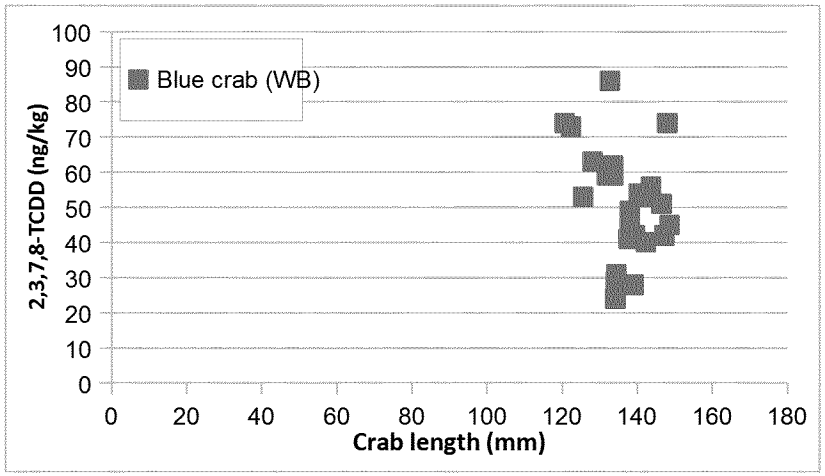


Figure 3-5. Blue crab length and whole-body 2,3,7,8-TCDD concentrations

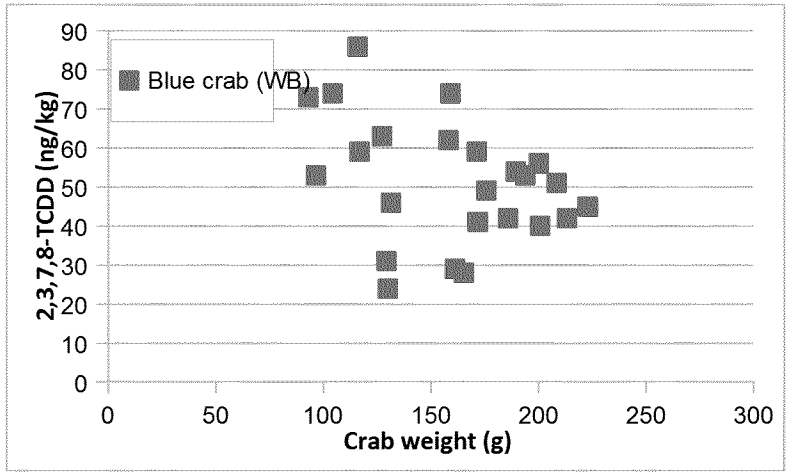


Figure 3-6. Blue crab weight and whole-body 2,3,7,8-TCDD concentrations

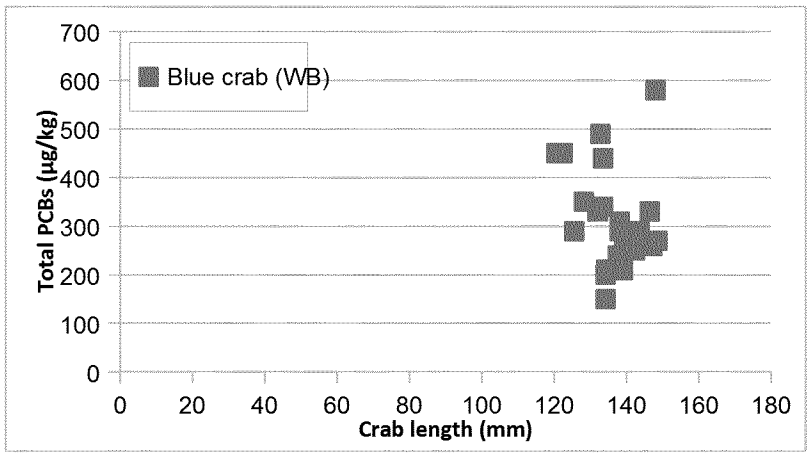


Figure 3-7. Blue crab length and whole-body total PCB concentrations

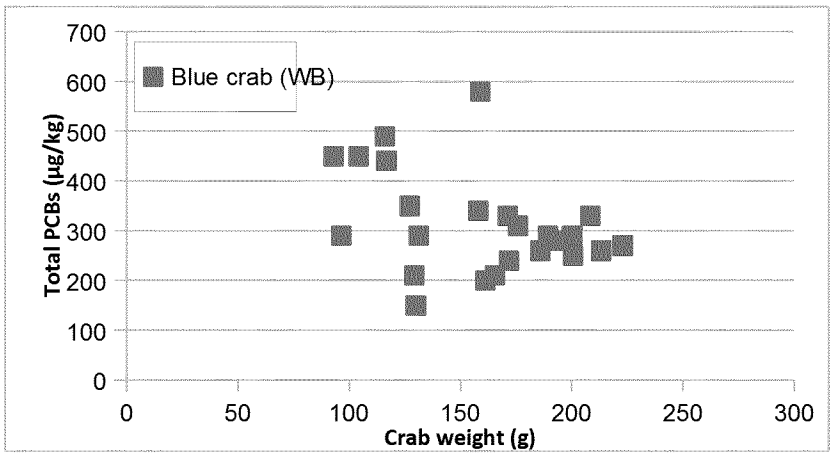


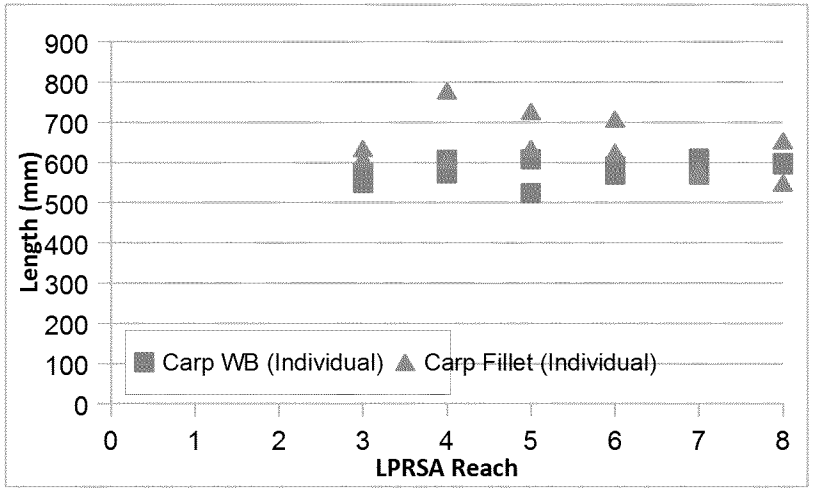
Figure 3-8. Blue crab weight and whole-body total PCB concentrations

3.2 CARP

Carp *(Cyprinus carpio*) are modeled in a compartment separate from benthic omnivores/ invertivores (catfish) in the bioaccumulation model because carp represent a unique exposure pathway based on their size, age, and feeding ecology.

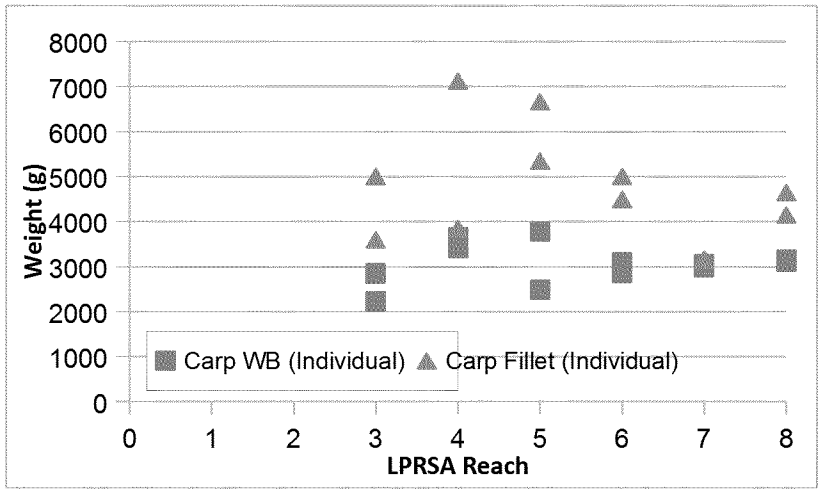
Carp tissue data were analyzed as individual fish collected from LPRSA Reaches 3 through 8 (RM 4 to RM 17.4). Both carp fillet and whole-body samples were collected (from different fish) and analyzed.[3] Carp analyzed as fillets were generally larger (in length and weight) than those analyzed as whole-body samples (Figures 3-9 and 3-10). Only carp whole-body data were used in the bioaccumulation model calibration, although Figures 3-9 and 3-10 show fish sizes for fillet data for informational purposes. Figures 3-11 through 3-16 present carp whole-body 2,3,7,8-TCDD and total PCB concentrations. Note that only samples from Reaches 4 to 8 (RM 6 to RM 17.4) were included in the calibration dataset, consistent with the modeling area for carp (see Section 3.2.4 of the main report). Thus, the two samples collected downstream of RM 6 were not included in the calibration dataset; however, data from these samples are presented in Figures 3-9 through 3-16 for informational purposes.

[3] For some other LPRSA fish for which fillets were analyzed, the fillet and carcass data were derived from the same fish, and these data were mathematically reconstituted to derive whole-body concentration data.



Note: Fillet data and whole-body (WB) data below Reach 4 are shown for informational purposes; only whole-body data from Reach 4 and above were used to calibrate the bioaccumulation model.

Figure 3-9. Length of individual carp in analytical samples by LPRSA reach



Note: Fillet data and whole-body (WB) data below Reach 4 are shown for informational purposes; only whole-body data from Reach 4 and above were used to calibrate the bioaccumulation model.

Figure 3-10. Weight of individual carp in analytical samples by LPRSA reach

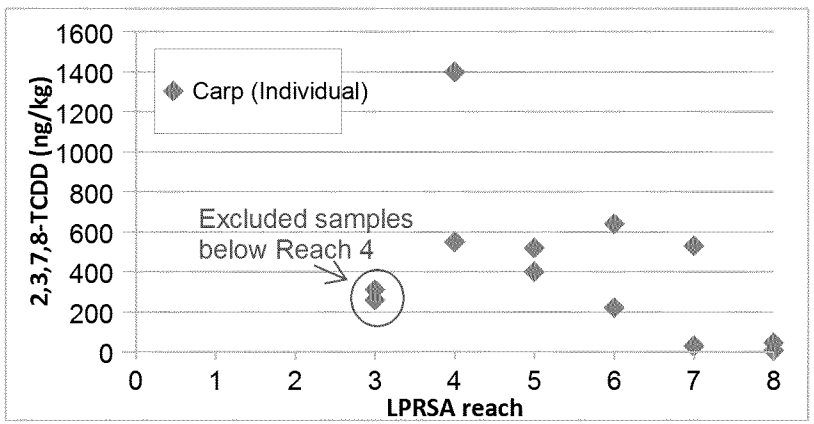


Figure 3-11. Carp whole-body 2,3,7,8-TCDD concentrations by LPRSA reach

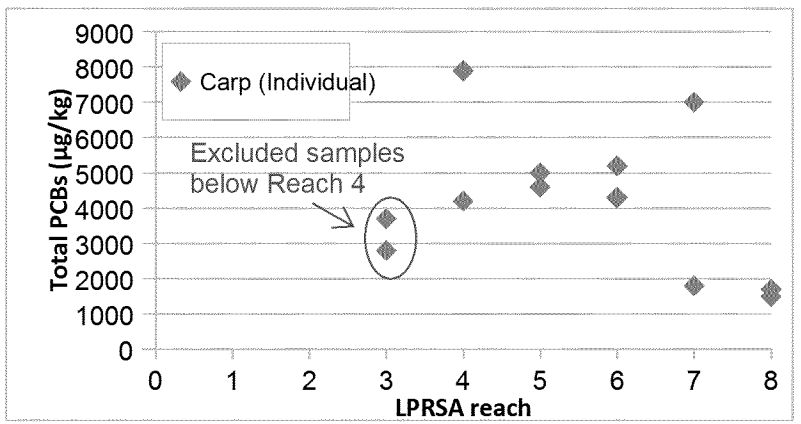
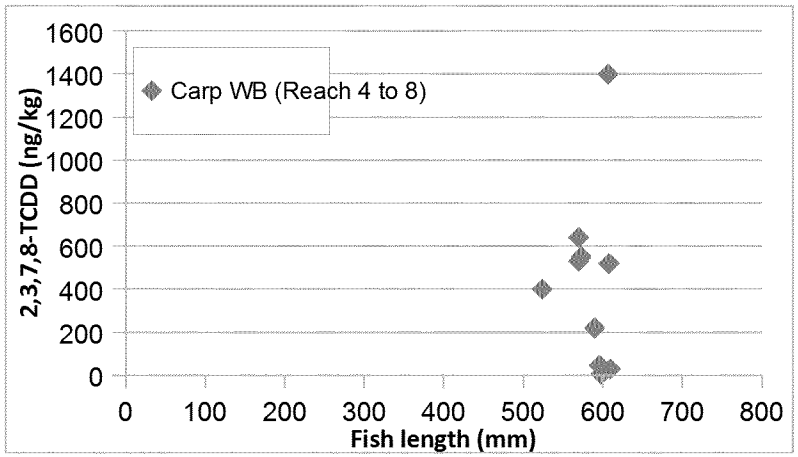
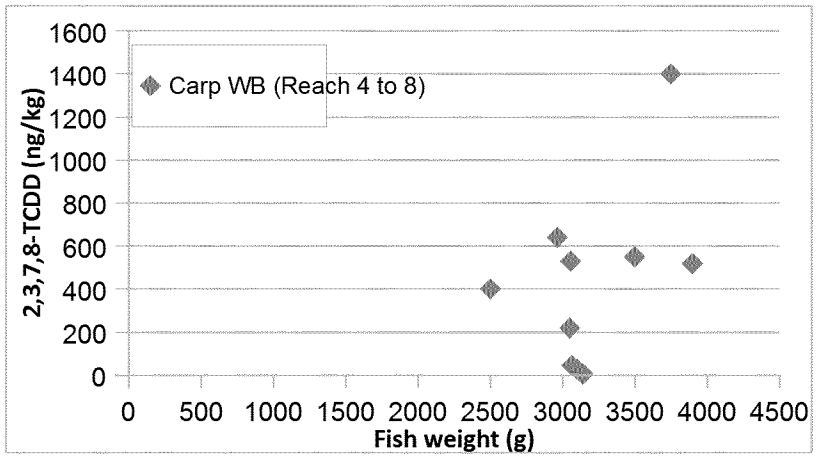


Figure 3-12. Carp whole-body total PCB concentrations by LPRSA reach



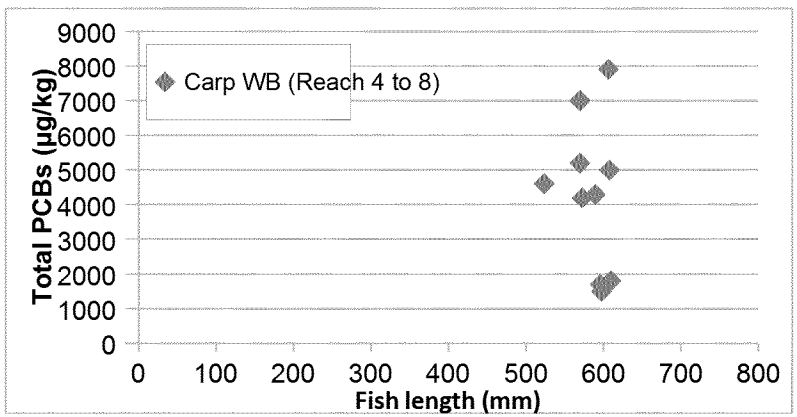
Note: Graph presents only carp data included in calibration dataset.

Figure 3-13. Carp length and whole-body 2,3,7,8-TCDD concentrations



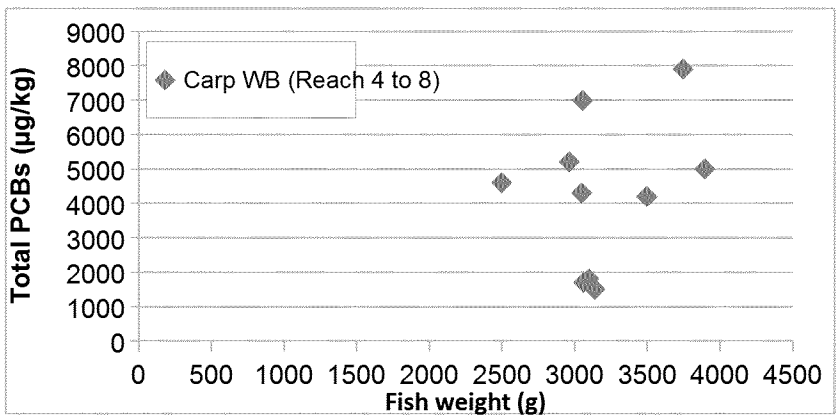
Note: Graph presents only carp data included in calibration dataset.

Figure 3-14. Carp weight and whole-body 2,3,7,8-TCDD concentrations



Note: Graph presents only carp data included in calibration dataset.

Figure 3-15. Carp length and whole-body total PCB concentrations



Note: Graph presents only carp data included in calibration dataset.

Figure 3-16. Carp weight and whole-body total PCB concentrations

3.3 CATFISH

The catfish compartment of the bioaccumulation model included both white catfish (*Ictalurus catus*) and channel catfish (*Ictalurus punctatus*). These catfish species have similar life histories and diets. In addition, the channel and white catfish collected in the LPRSA were similar in size (see Figures 3-17 and 3-18). Both channel and white catfish are opportunistic feeders that prey on whatever is available, including larger invertebrates such as amphipods, crayfish, and mollusks, as well as insects and small fish (NJDEP 2001; Wellborn 1988; California Fish Website 2013; Turner 1966b). Both white and channel catfish are predominately benthic feeders that consume some portion of sediment and detritus in their diet. Channel catfish have a lower tolerance for salinity than do white catfish, and therefore may have a smaller exposure area within the LPRSA than do white catfish. White catfish were collected in lower areas of the LPRSA (below RM 8[4]), where there is higher salinity.

Only white and channel catfish whole-body (i.e., reconstituted) data were evaluated in the bioaccumulation model calibration. Catfish whole-body data were based on the analysis of individual fish for both fillet and carcass tissue. Whole-body concentrations were mathematically reconstituted based on the fillet and carcass weights and concentrations.

Figures 3-19 through 3-24 present catfish whole-body tissue 2,3,7,8-TCDD and total PCB concentrations. Although concentrations in white catfish collected in Reaches 2 through 4 ranged greater than those in white and channel catfish collected in Reaches 5 through 8, average concentrations in white and channel catfish were similar in areas of the LPRSA where both species were collected. Only samples from Reaches 3 to 8 (i.e., RM 4 to RM 17.4) were included in the calibration dataset, consistent with the modeling area for catfish (see Section 3.2.4 of the main report). Thus, the one sample collected downstream of RM 4 was not included in the calibration dataset; however, data from this sample are presented in Figures 3-17 through 3-24 for informational purposes.

[4] LPRSA Reach 5 extends from RM 8 to RM 10.

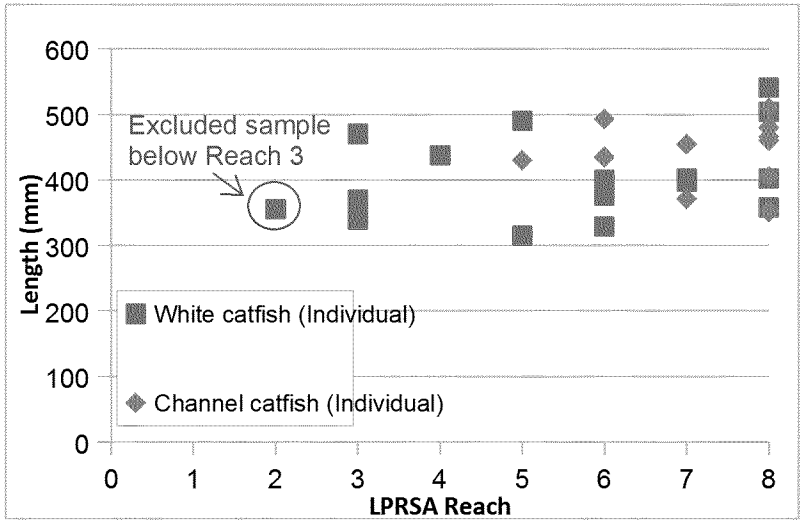


Figure 3-17. Length of individual catfish in analytical samples by LPRSA reach

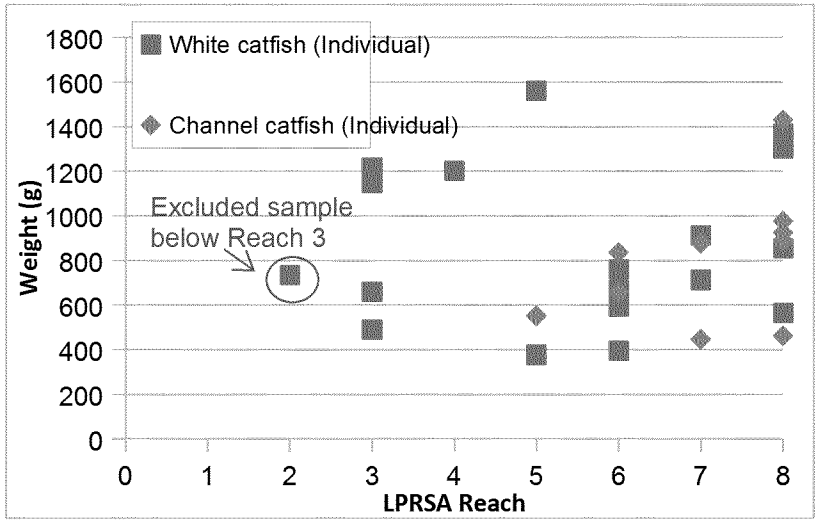


Figure 3-18. Weight of individual catfish in analytical samples by LPRSA reach

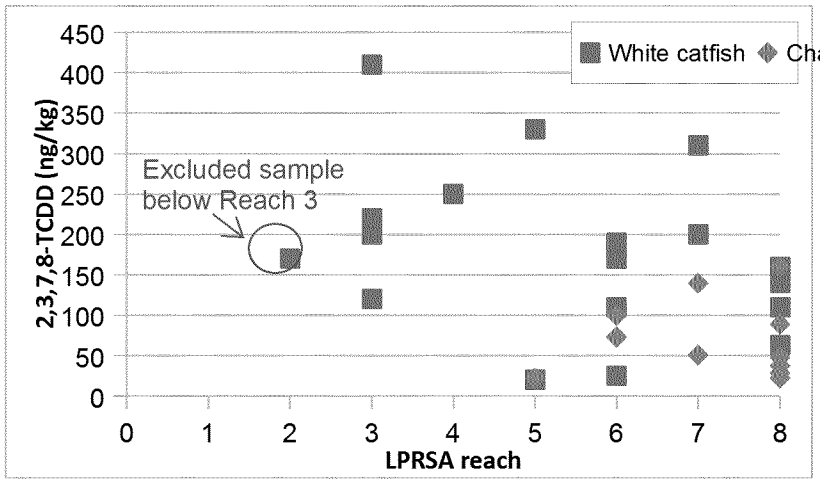


Figure 3-19. Catfish whole-body 2,3,7,8-TCDD concentrations by LPRSA reach

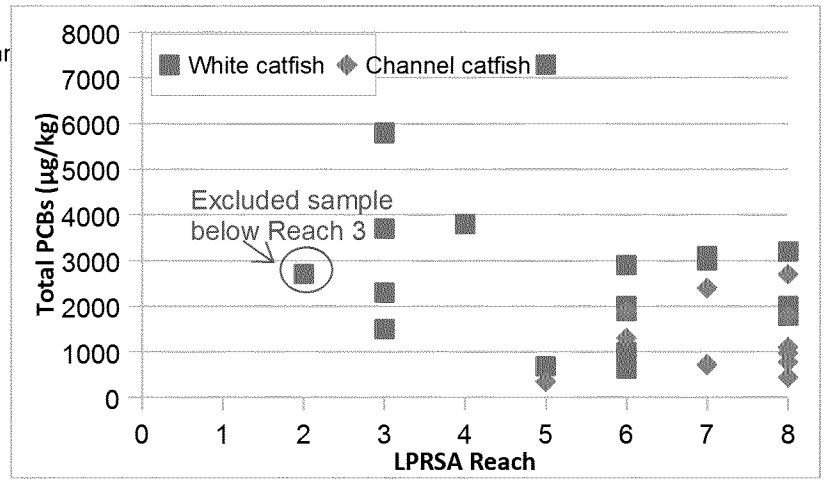
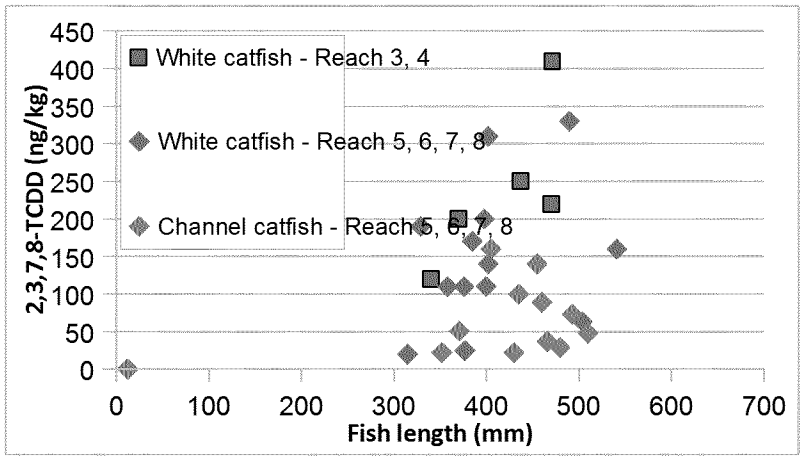
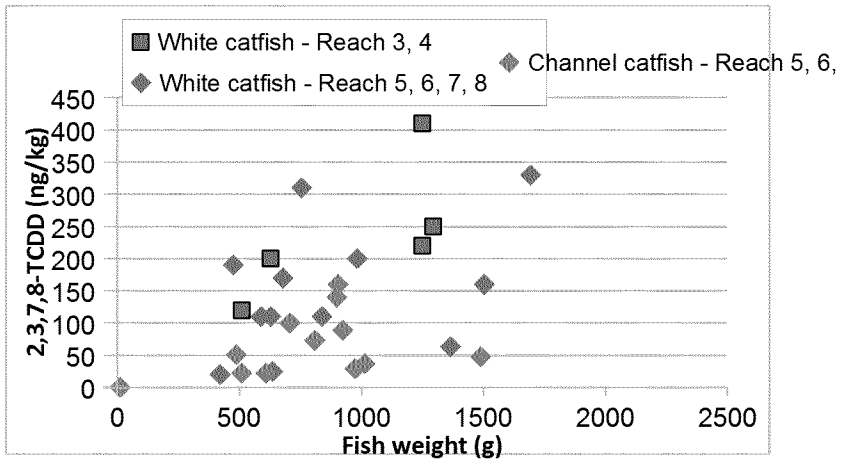


Figure 3-20. Catfish whole-body total PCB concentrations by LPRSA reach



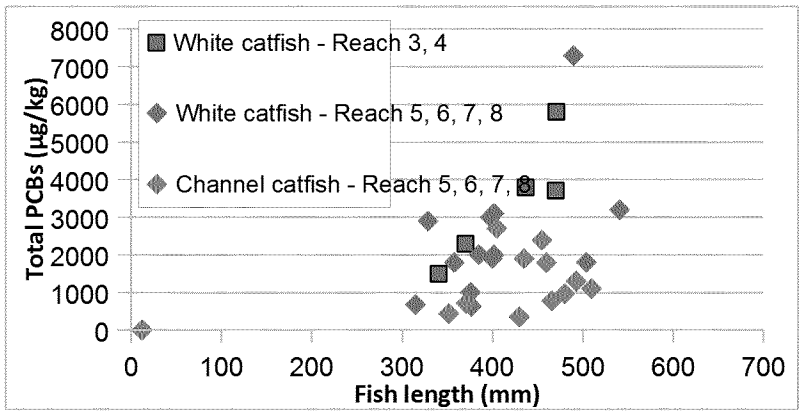
Note: Graph presents only catfish data included in calibration dataset.

Figure 3-21. Catfish length and whole-body 2,3,7,8-TCDD concentrations



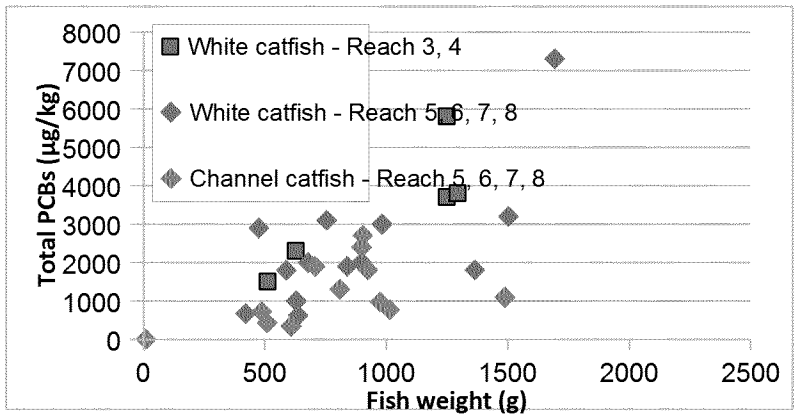
Note: Graph presents only catfish data included in calibration dataset.

Figure 3-22. Catfish weight and whole-body 2,3,7,8-TCDD concentrations



Note: Graph presents only catfish data included in calibration dataset.

Figure 3-23. Catfish length and whole-body total PCB concentration



Note: Graph presents only catfish data included in calibration dataset.

Figure 3-24. Catfish weight and whole-body total PCB concentrations

3.4 WHITE PERCH

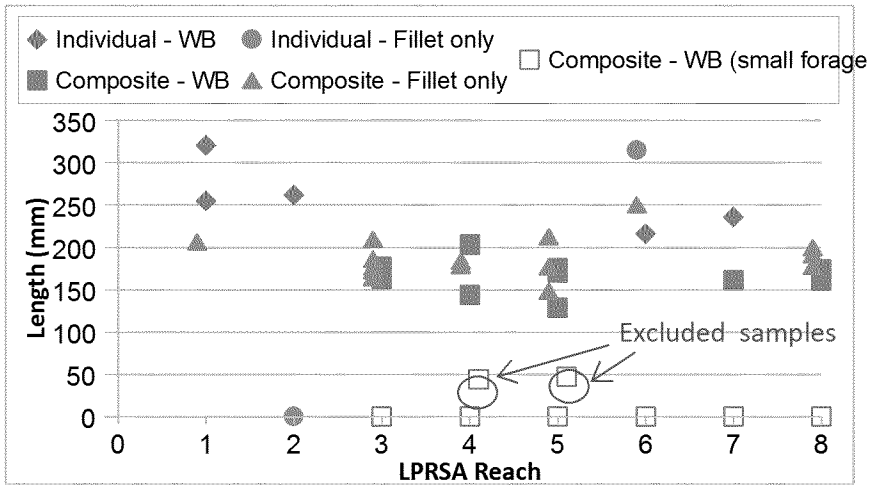
White perch (*Morone americana*) are included in the bioaccumulation model to represent small invertivorous fish. White perch tissue data were analyzed as individual fish and fish composites for white perch collected from throughout the LPRSA; individual and composite samples were analyzed one of three ways:

- Fillet-only samples
- Fillet and carcass samples (analytical results were used to mathematically reconstitute whole-body concentrations)
- Whole-body samples

White perch analyzed as fillet-only samples were generally within the size range (in length and weight) of white perch analyzed as whole-body samples (Figures 3-25 and 3-26). Only white perch whole-body data were used in the bioaccumulation model calibration, although Figures 3-25 and 3-26 show fish sizes for fillet data for informational purposes. The two white perch samples analyzed as part of the 2010 small forage fish collection effort (Windward [in prep]-c) were not included in the white perch calibration dataset[5] because these samples were based on white perch that were much smaller in size than the white perch collected in 2009 (Windward [in prep]-b) (see Figures 3-25 and 3-26). The white perch collected in 2009 are thought to better represent the size of perch caught and consumed by people; the creel/angler survey conducted along the LPRSA from 2011 to 2013 (AECOM [in prep]) reported that white perch collected for consumption (n = 6) ranged in size from 165 to 180 mm.

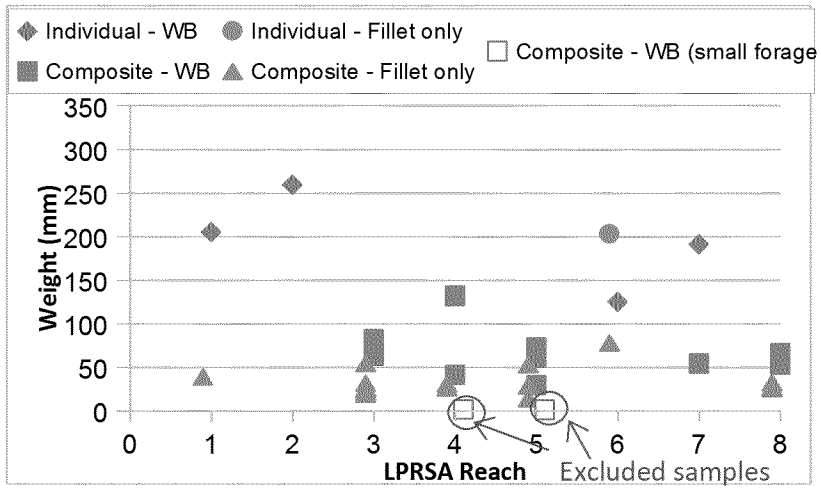
Whole-body data from both the whole-body samples and the reconstituted fillet and carcass samples were used in the bioaccumulation model. Figures 3-27 through 3-32 present white perch whole-body 2,3,7,8-TCDD and total PCB concentrations (excluding the two samples identified in Figures 3-25 and 3-26).

[5] Only one of the two white perch composite samples collected during the 2010 small forage fish sampling event was included in the small forage fish calibration dataset; the other sample was excluded given the wide range of fish sizes included in the composite sample (Section 4.2 of this appendix, which discusses the small forage fish dataset).



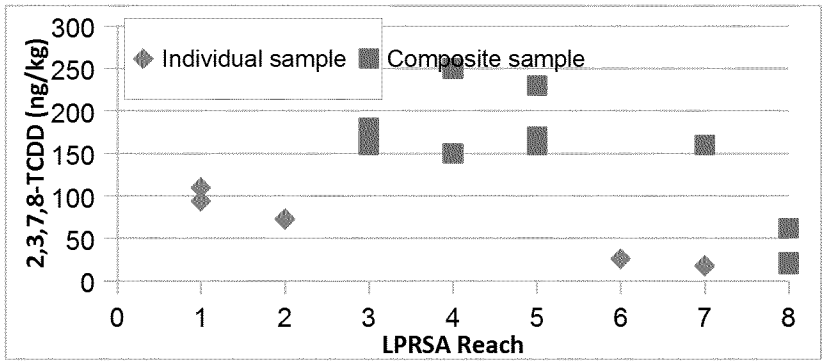
Note: Bars represent minimum and maximum values in composite sample. Fillet data are shown for informational purposes; only whole-body data collected in 2009 were used to calibrate the bioaccumulation model.

Figure 3-25. Length of white perch in analytical samples by LPRSA reach



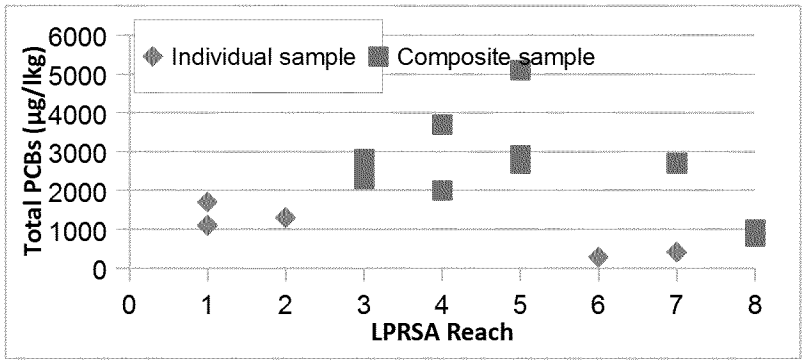
Note: Bars represent minimum and maximum values in composite sample. Fillet data are shown for informational purposes; only whole-body data collected in 2009 were used to calibrate the bioaccumulation model.

Figure 3-26. Weight of white perch in analytical samples by LPRSA reach



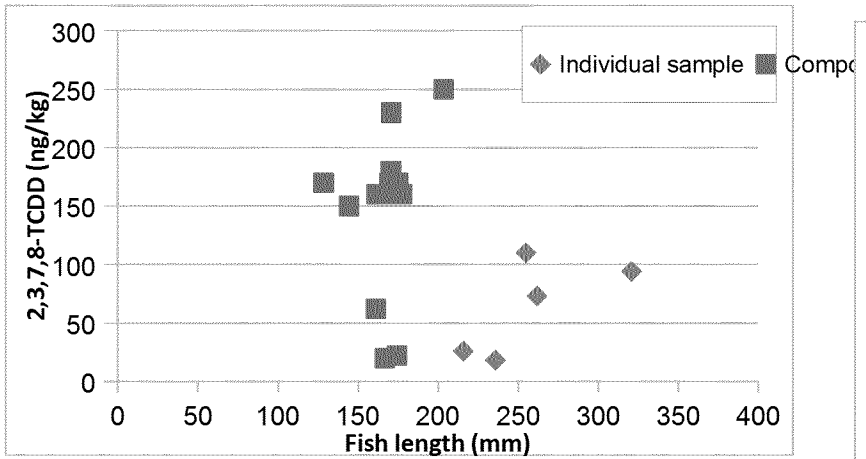
Note: Graph presents only white perch data included in calibration dataset.

Figure 3-27. White perch whole-body 2,3,7,8-TCDD concentrations by LPRSA reach



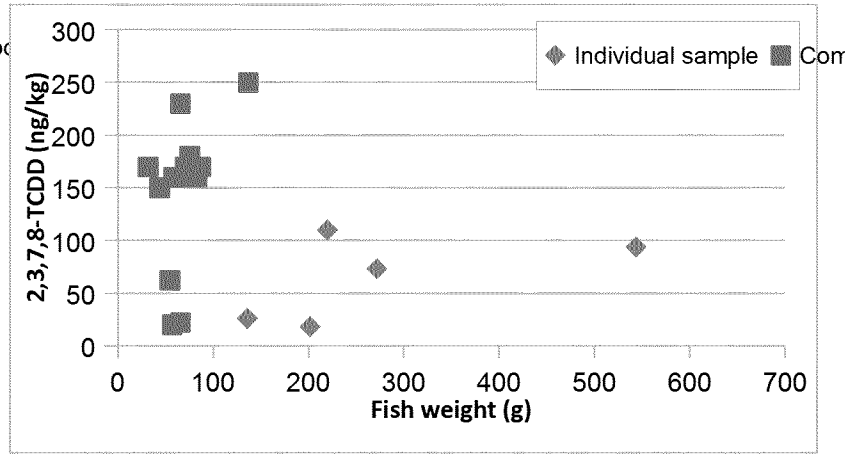
Note: Graph presents only white perch data included in calibration dataset.

Figure 3-28. White perch whole-body total PCB concentrations by LPRSA reach



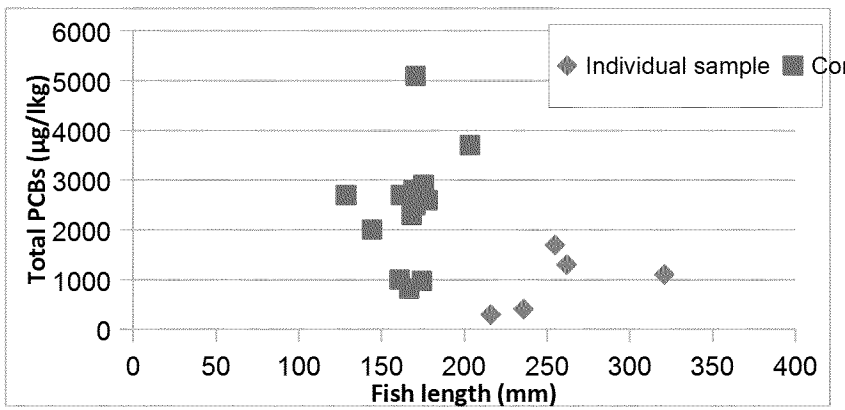
Note: Graph presents only white perch data included in calibration dataset.

Figure 3-29. White perch length and whole-body 2,3,7,8-TCDD concentrations



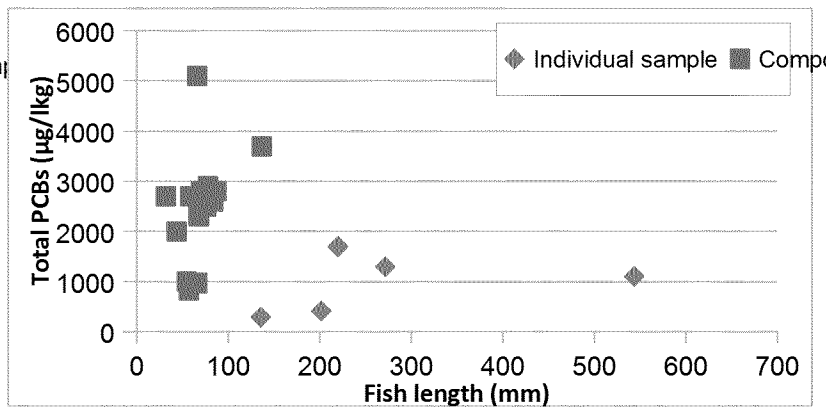
Note: Graph presents only white perch data included in calibration dataset.

Figure 3-30. White perch weight and whole-body 2,3,7,8-TCDD concentrations



Note: Graph presents only white perch data included in calibration dataset.

Figure 3-31. White perch length and whole-body total PCB concentrations



Note: Graph presents only white perch data included in calibration dataset.

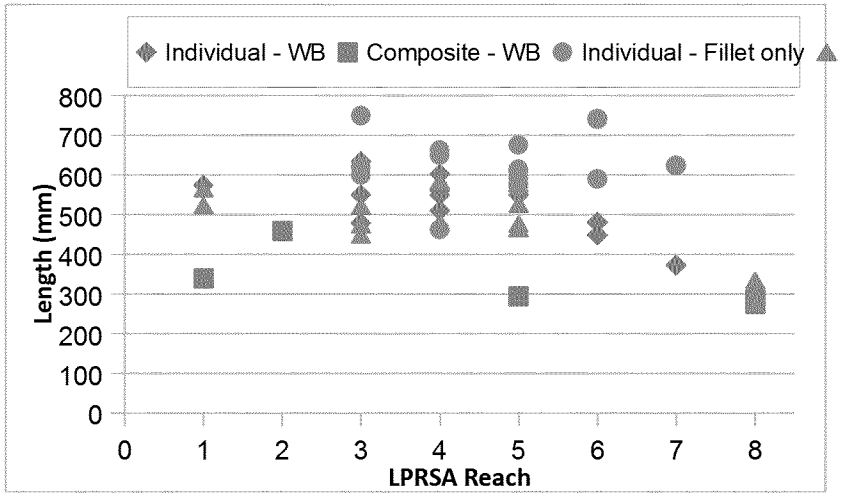
Figure 3-32. White perch weight and whole-body total PCB concentrations

3.5 AMERICAN EEL

American eel (*Anguilla rostrata*) were included in the bioaccumulation model to represent piscivorous fish found throughout the LPRSA. Like white perch, American eel tissue data were analyzed based on individual fish and fish composites collected from throughout the LPRSA; individual and composite samples were analyzed one of three ways:

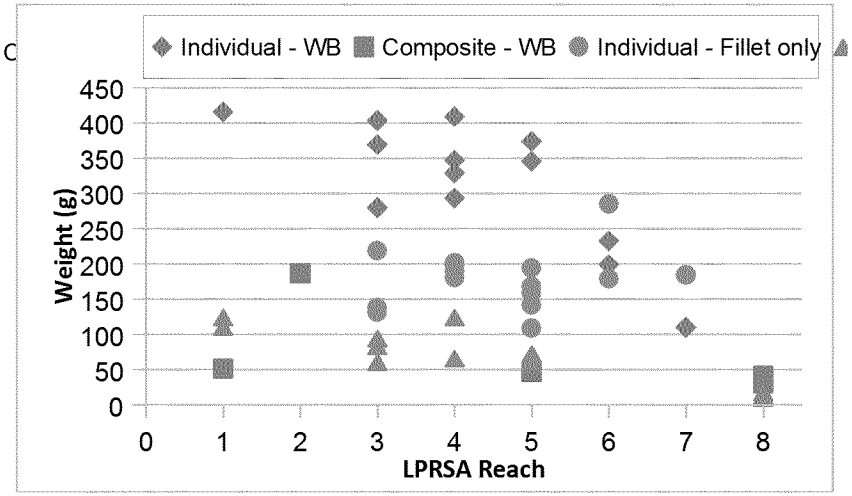
- Fillet-only samples
- Fillet and carcass samples (analytical results were used to mathematically reconstitute whole-body concentrations)
- Whole-body samples

American eel analyzed as fillet-only samples were generally similar in length but greater in weight than American eel analyzed as whole-body samples (Figures 3-33 and 3-34). Only American eel whole-body data were used in the bioaccumulation model calibration, although Figures 3-33 and 3-34 show fish sizes for fillet data for informational purposes. Whole-body data from both the whole-body samples and the reconstituted fillet and carcass samples were used in the bioaccumulation model. All available American eel whole-body data were used, regardless of eel size, although the dietary assumptions used in the bioaccumulation model were generally based on larger (e.g., > 50 cm) eel. The inclusion of all American eel size classes in the calibration dataset is discussed in the uncertainty analysis (Section 4.2.5.2 of the main report). Figures 3-35 through 3-40 present American eel whole-body 2,3,7,8-TCDD and total PCB concentrations.



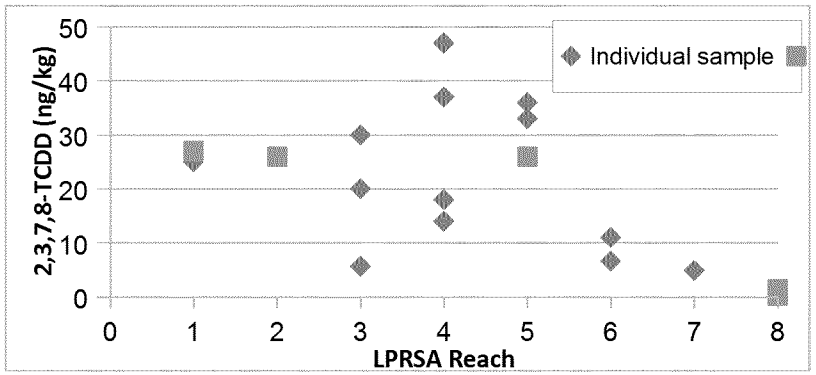
Note: Bars represent minimum and maximum values in composite sample.
Fillet data are shown for informational purposes; only whole-body data were used to calibrate the bioaccumulation model.

Figure 3-33. Length of American eel in analytical samples by LPRSA reach



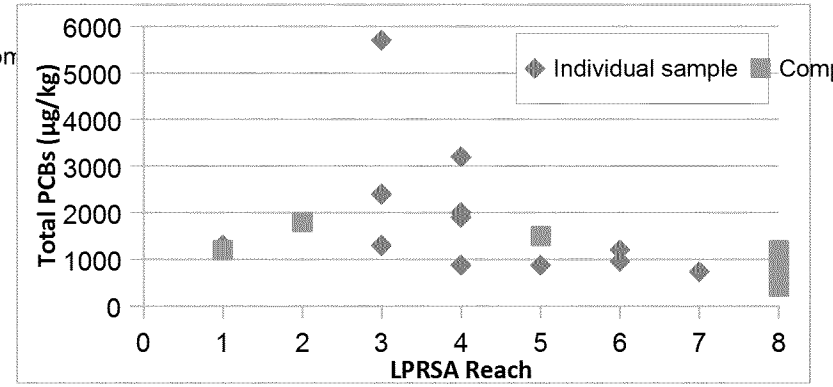
Note: Bars represent minimum and maximum values in composite sample.
Fillet data are shown for informational purposes; only whole-body data were used to calibrate the bioaccumulation model.

Figure 3-34. Weight of American eel in analytical samples by LPRSA reach



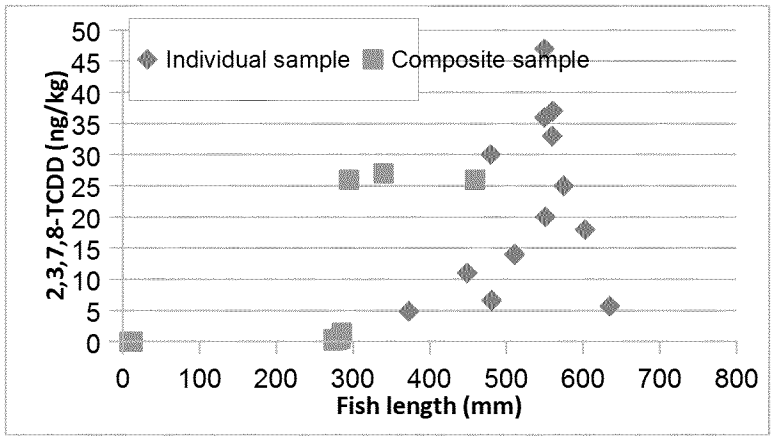
Note: All American eel whole-body data included in calibration dataset.

Figure 3-35. American eel whole-body 2,3,7,8-TCDD concentrations by LPRSA reach



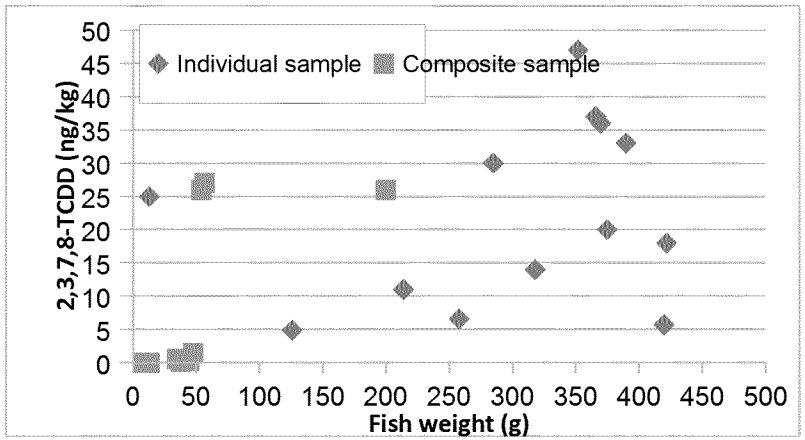
Note: All American eel whole-body data included in calibration dataset.

Figure 3-36. American eel whole-body total PCB concentrations by LPRSA reach



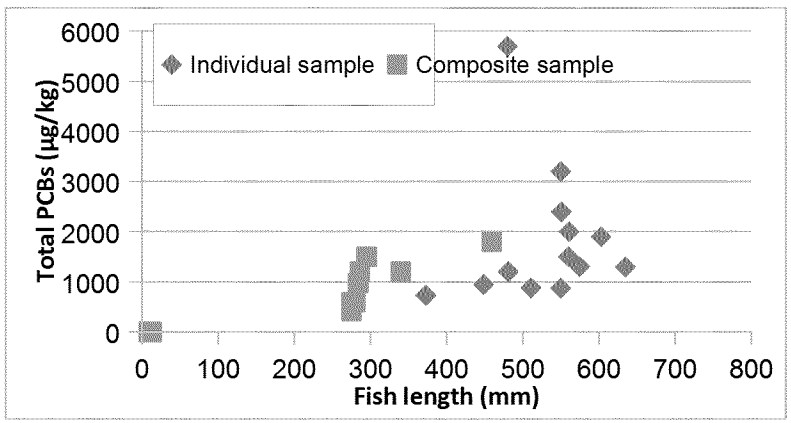
Note: All American eel whole-body data included in calibration dataset.

Figure 3-37. American eel length and whole-body 2,3,7,8-TCDD concentrations



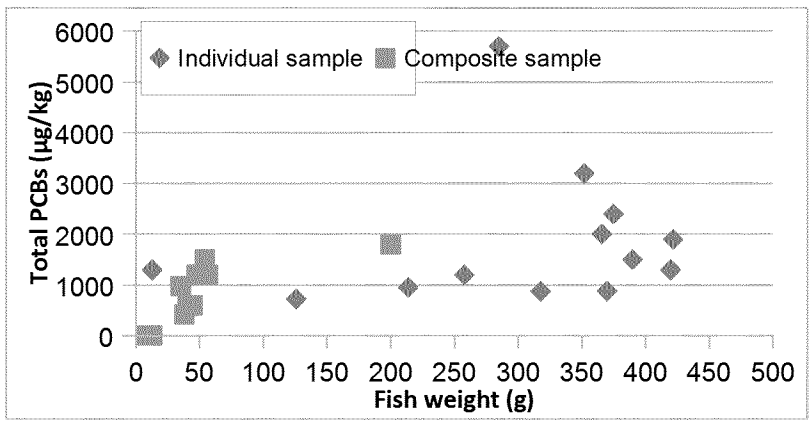
Note: All American eel whole-body data included in calibration dataset.

Figure 3-38. American eel weight and whole-body 2,3,7,8-TCDD concentrations



Note: All American eel whole-body data included in calibration dataset.

Figure 3-39. American eel length and whole-body total PCB concentrations



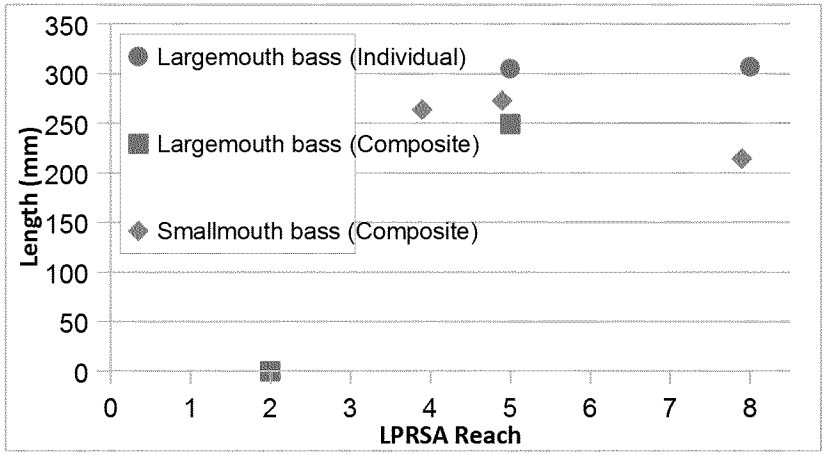
Note: All American eel whole-body data included in calibration dataset.

Figure 3-40. American eel weight and whole-body total PCB concentrations

3.6 FRESHWATER BASS

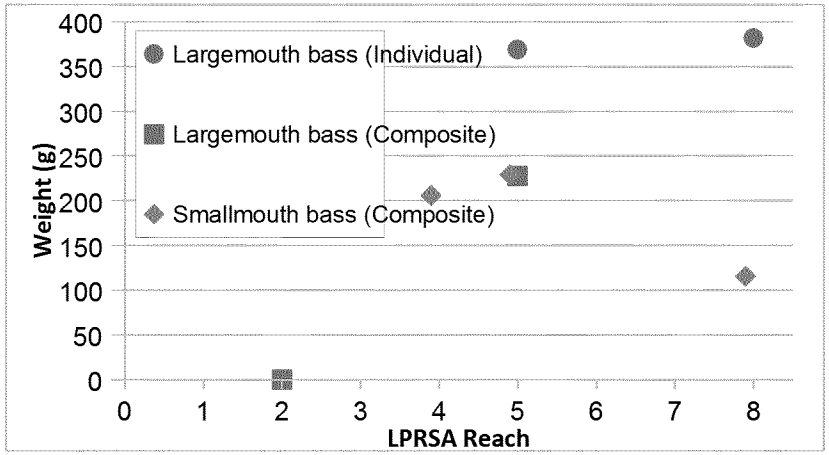
The freshwater bass compartment of the bioaccumulation model includes both smallmouth bass (*Micropterus dolomieui*) and largemouth bass (*Micropterus salmoides*). Smallmouth and largemouth bass have similar life histories and diets. Both are opportunistic feeders and primarily feed on small fish and invertebrates based on their availability (George and Hadley 1979; Turner 1966a; Wydoski and Whitney 1979). In addition, smallmouth and largemouth bass collected in the LPRSA for analysis were generally similar in size (Figures 3-41 and 3-42). Both were limited to the upper portion (above RM 6) of the LPRSA.

Available smallmouth and largemouth bass whole-body data were evaluated in the bioaccumulation model calibration; however, data were limited to three smallmouth and three largemouth bass whole-body samples. Freshwater bass whole-body (both fillet and carcass tissue) data were based on the analysis of individual fish or fish composites (composed of two or three fish). Whole-body concentrations that were mathematically reconstituted based on the fillet and carcass weights and concentrations were used in the bioaccumulation model. Figures 3-43 through 3-48 present the whole-body bass 2,3,7,8-TCDD and total PCB concentrations.



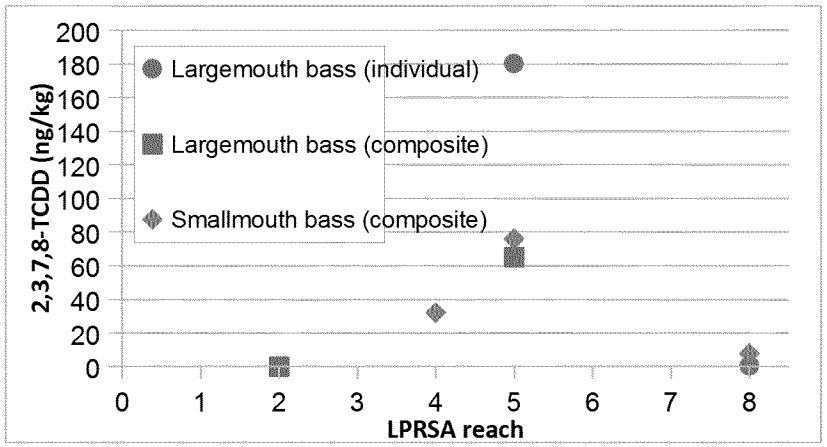
Note: Bars represent minimum and maximum values in composite sample.

Figure 3-41. Length of freshwater bass in analytical samples by LPRSA reach



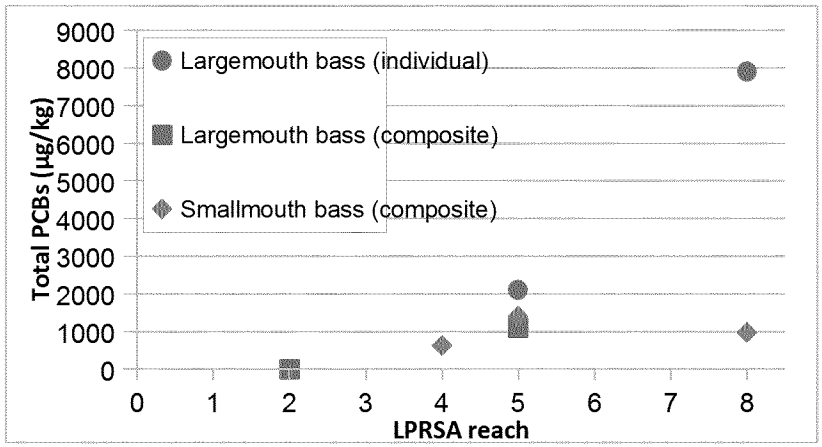
Note: Bars represent minimum and maximum values in composite sample.

Figure 3-42. Weight of freshwater bass in analytical samples by LPRSA reach



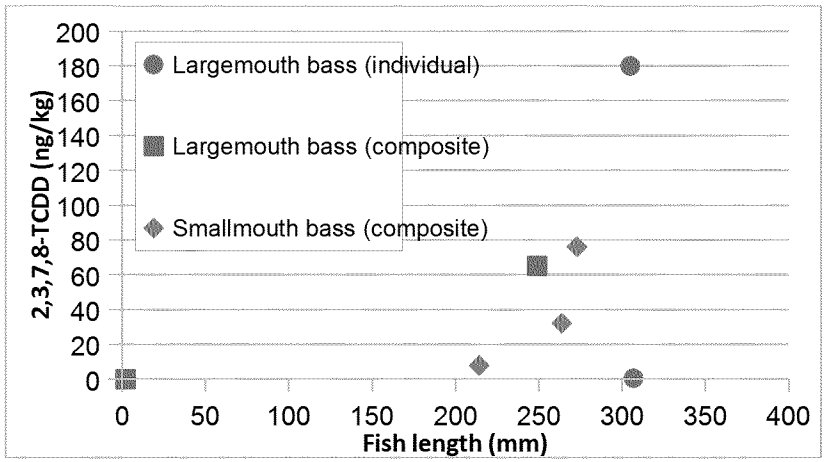
Note: All freshwater bass whole-body data included in calibration dataset.

Figure 3-43. Freshwater bass whole-body 2,3,7,8-TCDD concentrations by LPRSA reach



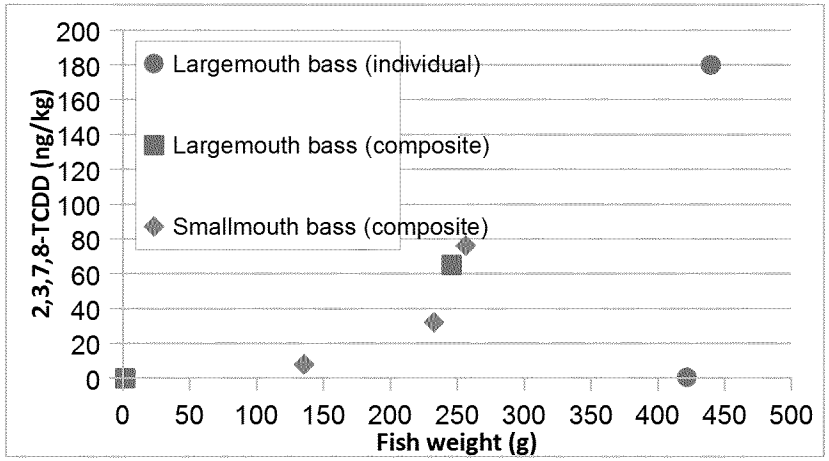
Note: All freshwater bass whole-body data included in calibration dataset.

Figure 3-44. Freshwater bass whole-body total PCB concentrations by LPRSA reach



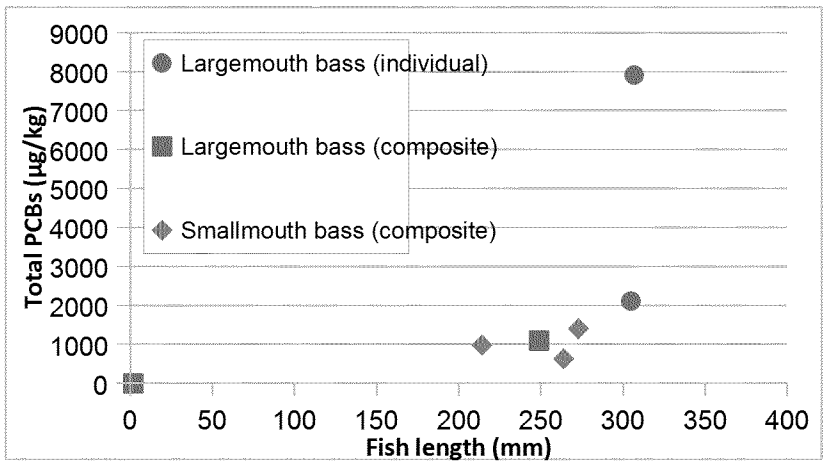
Note: All freshwater bass whole-body data included in calibration dataset.

Figure 3-45. Freshwater bass length and whole-body 2,3,7,8-TCDD concentrations



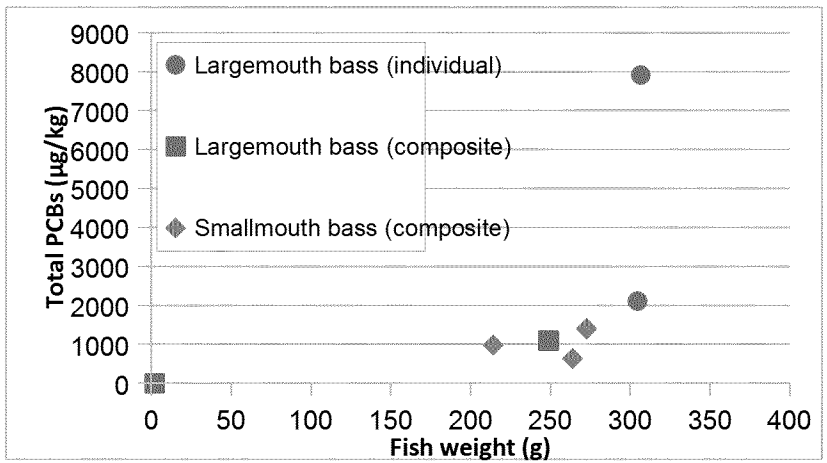
Note: All freshwater bass whole-body data included in calibration dataset.

Figure 3-46. Freshwater bass weight and whole-body 2,3,7,8-TCDD concentrations



Note: All freshwater bass whole-body data included in calibration dataset.

Figure 3-47. Freshwater bass length and whole-body total PCB concentrations



Note: All freshwater bass whole-body data included in calibration dataset.

Figure 3-48. Freshwater bass weight and whole-body total PCB concentrations

4 Additional Data Evaluated in the Bioaccumulation Model

Tables 4-1 and 4-2 summarize the whole-body data available for additional fish species and invertebrates that were not used to calibrate the bioaccumulation model because they were not target species or lacked sufficient current LPRSA data for calibration. These data were evaluated in the uncertainty analysis of the bioaccumulation model. Details regarding these data and their sources are provided in Sections 4.1 to 4.4.

Table 4-1. Summary of tissue samples for additional fish and invertebrate species evaluated in the bioaccumulation model uncertainty analysis

LPRSA Segment	Number of Whole-Body Samples													
	Filter-Feeding Fish[a]		Small Forage Fish[b]		Brown Bullhead		White Sucker		Northern Pike		C/O[c]		DEP[d]	
	C	I	C	I	C	I	C	I	C	I	C	I	C	I
RM 0 – RM 2 (Reach 1)	3	-	2	-	-	-	-	-	-	-	3	-	-	-
RM 2 – RM 4 (Reach 2)	-	-	6	-	-	-	-	-	-	-	1	-	-	-
RM 4 – RM 6 (Reach 3)	3	-	3	-	-	1	-	-	-	-	1	-	-	-
RM 6 – RM 8 (Reach 4)	1	-	5	-	-	1	-	1	-	-	-	-	3	-
RM 8 – RM 10 (Reach 5)	1	-	4	-	-	-	-	2	-	-	-	-	3	-
RM 10 – RM 12 (Reach 6)	-	-	2	-	-	3	-	-	-	1	-	-	2	-
RM 12 – RM 14 (Reach 7)	1	-	-	-	-	1	-	-	-	-	-	-	5	-
RM 14 – RM 17.4 (Reach 8)	-	-	3	-	-	-	-	2	-	-	-	-	1	-
Site-wide total	**9**	**0**	**25**	**0**	**0**	**6**	**0**	**5**	**0**	**1**	**5**	**0**	**14**	**0**
	9		**25**				**5**		**1**		**5**		**14**	

[a] Filter-feeding fish includes small gizzard shad (n = 3) data.

[b] Small forage fish includes mummichog (n = 18), white perch (n=1), silver shiner (n = 1), spottail shiner (n = 1), and mixed forage fish (n = 4) data.

[c] Estuarine worm (*Nereis virens*) laboratory bioaccumulation tissue data.

[d] Freshwater worm (*Lumbriculus variegatus*) laboratory bioaccumulation tissue data.

C – composite sample
I – individual fish sample
C/O – benthic invertebrate carnivore/omnivore
LPRSA – Lower Passaic River Study Area
DEP – benthic invertebrate deposit feeder
RM – river mile

Table 4-2. Summary of empirical concentrations for additional tissue evaluated in the bioaccumulation model uncertainty analysis

Species	Modeling Area	No. of Samples	Concentration[a]					
			2,3,7,8-TCDD (ng/kg ww)		Tetrachlorobiphenyl (µg/kg ww)		Total PCB Congeners (µg/kg ww)	
			Mean	SD	Mean	SD	Mean	SD

Filter-feeding fish[b]	site-wide[c]	3	30	17	120	40	380	120
Small forage fish[b]	site-wide	25	37	26	120	55	510	200
Brown bullhead	RM 4-17.4	6	91	71	190	160	870	610
White sucker	RM 6-17.4	5	59	53	260	140	1,500	910
Northern pike	RM 6-17.4	1	95	na	430	na	2,000	na
C/O[d]	site-wide[e]	5	6.1	7.3	15	16	53	43
DEP[f]	RM 6-17.4	14	27	37	51	48	180	160

[a] Based on detected concentrations only.

[b] Filter-feeding fish includes young-of-the year Atlantic menhaden and small gizzard shad data; only LPRSA gizzard shad data were available.

[b] Small forage fish includes mummichog (n = 18), white perch (1 sample), silver shiner (n = 1), and spottail shiner (n = 1), and mixed forage fish (n = 4) data.

[c] Samples were available only between RM 6 and RM 14 (Reaches 4 through 7).

[d] Estuarine worm (*Nereis virens*) laboratory bioaccumulation tissue data.

[e] Samples were available only between RM 0 and RM 6 (Reaches 1 through 3).

[f] Freshwater worm (*Lumbriculus variegatus*) laboratory bioaccumulation tissue data.

C/O – benthic invertebrate carnivore/omnivore
DEP – benthic invertebrate deposit feeder
LPRSA – Lower Passaic River Study Area
na – not applicable
PCB – polychlorinated biphenyl
RM – river mile
SD – standard deviation
TCDD - tetrachlorodibenzo-*p*-dioxin
ww – wet weight

4.1 SMALL FILTER-FEEDING FISH

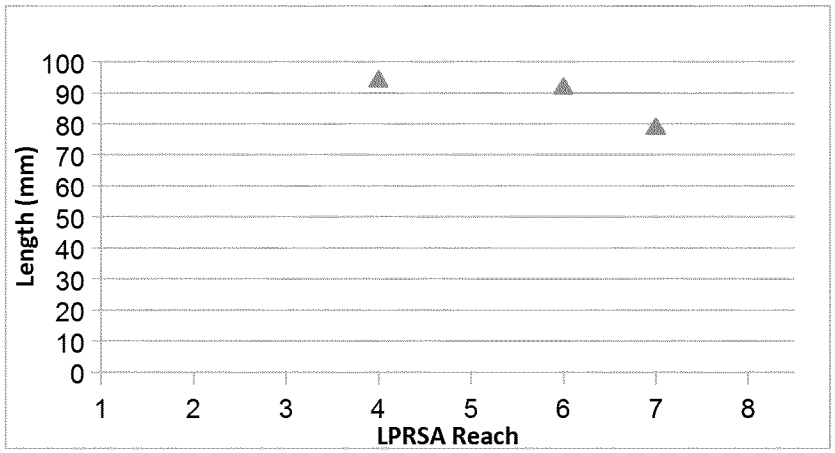
The small filter-feeding fish compartment of the bioaccumulation model includes juvenile (young-of-the-year) Atlantic menhaden (*Brevoortia tyrannus*) and small gizzard shad (*Dorosoma cepedianum*).

Limited LPRSA data were available for filter-feeding fish; three whole-body composite samples were collected during the 2010 small forage fish sampling effort (Windward [in prep]-c). LPRSA data were available for adult Atlantic menhaden but not for juvenile Atlantic menhaden. Because current data were limited, filter-feeding fish data were not used in the calibration of the bioaccumulation model. Gizzard shad data were evaluated as part of the uncertainty assessment of the bioaccumulation model to estimate how well small filter-feeding tissue concentrations were estimated.

Figures 4-1 and 4-2 present data on the mean length and weight, respectively, of fish analyzed in the gizzard shad composite samples; individual fish ranged from 67 to 111 mm in length. Juvenile Atlantic menhaden data for the LPRSA were not available; however, in the general literature, juvenile Atlantic menhaden have been reported to range from 55 to 140 mm in length (Rogers and van den Avyle 1989), which is similar to the lengths of collected LPRSA gizzard shad. Figures 4-3 and 4-4 present gizzard shad 2,3,7,8-TCDD and total PCB concentrations. Adult Atlantic menhaden data[6] for total PCBs and 2,3,7,8-TCDD from the LPRSA 1999 sampling effort conducted by

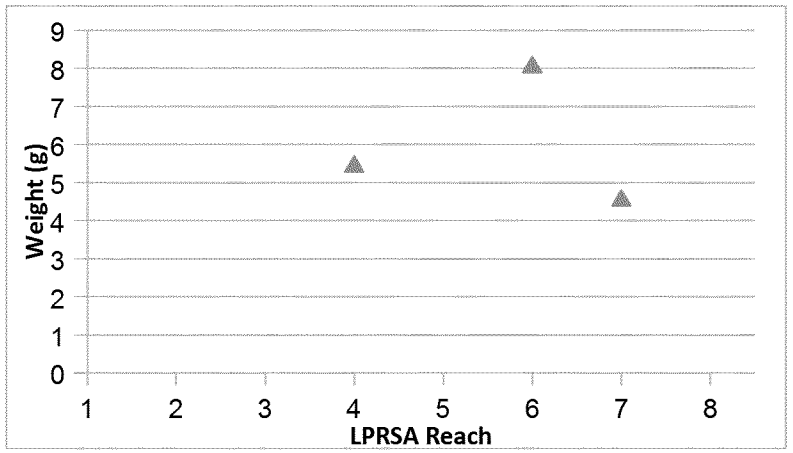
[6] Atlantic menhaded caught during the 1999 sampling effort at LPRSA locations were an average of 342 mm long in Reach 1 and 304 mm long in Reach 3 (BBL 2001). Atlantic menhaden caught from the LPRSA during the 2009 and 2010 fish community surveys (n = 149 fish with reported size data) ranged from 80 to 390 mm in size; only three of the fish were < 270 mm.

Tierra were available (BBL 2001); however, these fish were not expected to represent the size of fish consumed by higher trophic levels.



Note: Bars represent minimum and maximum values in composite sample.

Figure 4-1. Mean length of gizzard shad in analytical composite samples



Note: Bars represent minimum and maximum values in composite sample.

Figure 4-2. Mean weight of gizzard shad in analytical composite samples

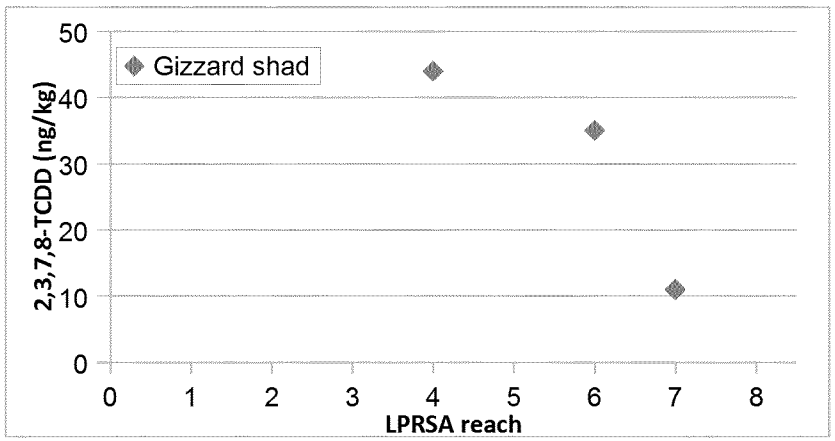


Figure 4-3. Gizzard shad whole-body 2,3,7,8-TCDD concentrations by LPRSA reach

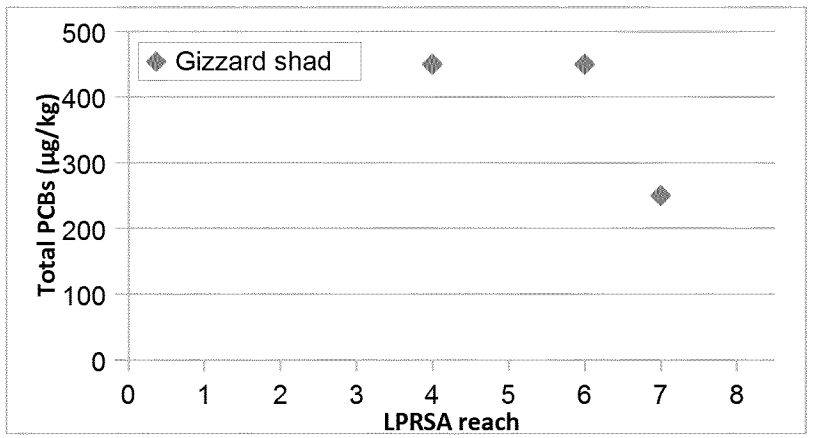


Figure 4-4. Gizzard shad whole-body total PCB concentrations by LPRSA reach

4.2 SMALL FORAGE FISH

The small forage fish compartment of the bioaccumulation model includes primarily mummichog (*Fundulus heteroclitus*), but it also includes other species, such as shiners (*Notropis* spp.), striped mullet (*Mugil cephalus*), and tesselated darter (*Etheostoma olmstedi*). Composite samples of small forage fish were analyzed for a number of species: mummichog (n = 18), gizzard shad (n = 3), pumpkinseed (n = 1), silver shiner (n = 1), spottail shiner (n = 1), white perch (n = 2), and mixed forage fish composites (n = 4). Mixed forage fish samples were composed of multiple small forage fish species (Table 4-3).

Table 4-3. Composition of mixed forage fish samples

Sample ID	No. of Fish in Sample	Reach	RM	Fish Species
LPR4-MXWB-Comp01	26	4	7.0	smallmouth bass (n = 1), striped bass (n = 2), tessellated darter (n = 4), striped mullet (n = 2), gizzard shad (n = 10), spottail shiner (n = 6), and Atlantic silverside (n = 1)
LPR5-MXWB-Comp02	69	5	8.4	striped mullet (n = 1), white perch (n = 45), gizzard shad (n = 15), spottail shiner (n = 7), and inland silverside (n = 1)
LPR6-MXWB-Comp03	74	6	11.2	striped bass (n = 5), bluegill (n = 9), striped mullet (n = 5), white perch (n = 48), and Atlantic silverside (n = 7)
LPR8-MXWB-Comp04	18	8	14.2	smallmouth bass (n = 2), striped bass (n = 1), gizzard shad (n = 4), and inland silverside (n = 11)

ID – identification
RM – river mile

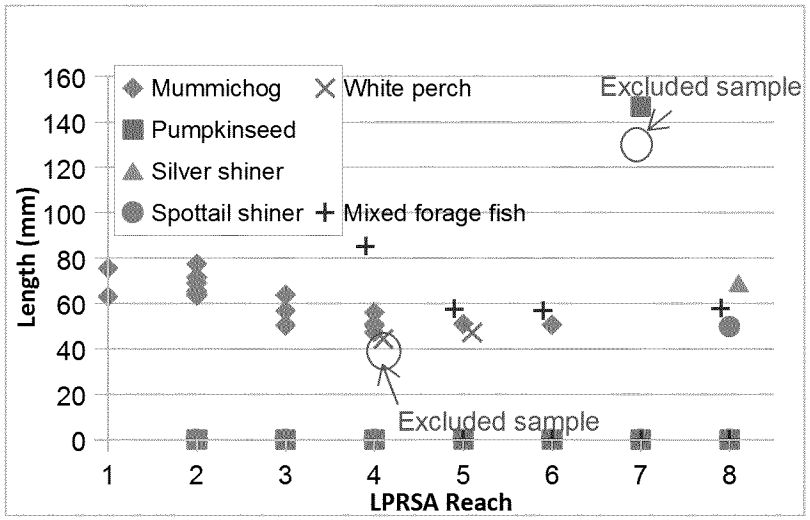
The small forage fish data used to calibrate the bioaccumulation model included only those fish samples that represented fish small enough to be preyed upon by other LPRSA fish and that were generally benthic feeding fish. Gizzard shad, although collected under the 2010 small forage fish sampling effort (Windward 2011), were excluded from the bioaccumulation calibration dataset for small forage fish because this species is more representative of filter-feeding fish, which were modeled as a separate compartment in the bioaccumulation model (see Section 4.1 for discussion of filter-feeding fish data). In addition, larger fish collected during the 2010 small forage fish sampling effort that did not represent appropriate prey for modeled LRPSA fish-eating fish were not included in the calibration dataset for small forage fish (Figures 4-5 and 4-6). Such samples included the single pumpkinseed composite sample[7] (composed of three fish ranging from 141 to 150 mm in length) and one of two white perch samples[8] that included 1 large fish (170 mm in length) and 120 smaller fish (ranging from 27 to 57 mm in length). Figures 4-7 through 4-12 present small forage

[7] The 2,3,7,8-TCDD and total PCB concentrations in the pumpkinseed sample excluded from the calibration dataset were 7.5 and 170 µg/kg, respectively.
[8] The 2,3,7,8-TCDD and total PCB concentrations in the white perch sample excluded from the calibration dataset were 160 and 1,800 µg/kg, respectively.

fish 2,3,7,8-TCDD and total PCB concentrations (excluding the two samples identified in Figures 4-5 and 4-6).

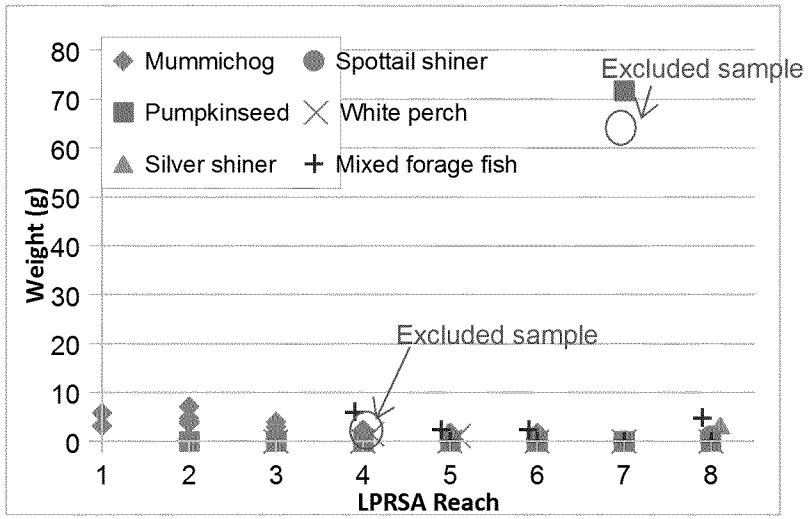
There is some uncertainty associated with the inclusion of the four mixed forage fish samples in the small forage fish calibration dataset, because a portion of these samples was made up of fish species (e.g., gizzard shad) that may be more representative of filter-feeding fish[9] than small forage fish. This uncertainty was considered in the evaluation of model calibration results, although 2,3,7,8-TCDD and total PCBs concentrations in mixed forage fish samples are within the range of those in the other small forage fish samples (Figure 4-7 through 4-12).

[9] Filter-feeding fish were modeled as a separate compartment in the bioaccumulation model.



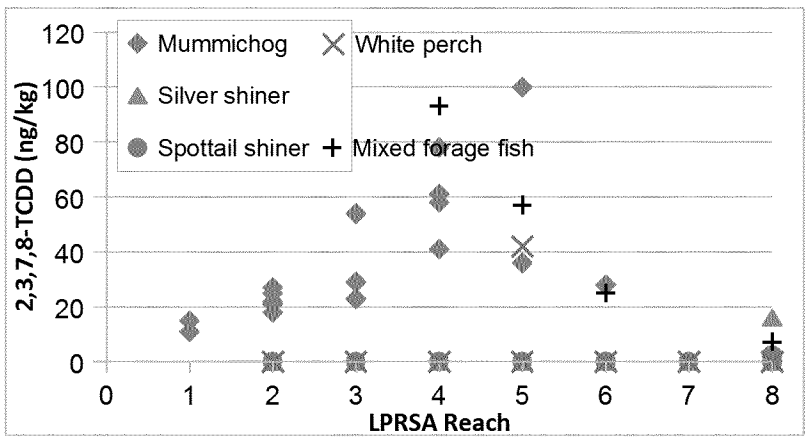
Note: Bars represent minimum and maximum values in composite sample.

Figure 4-5. Mean length of small forage fish in analytical samples by LPRSA reach



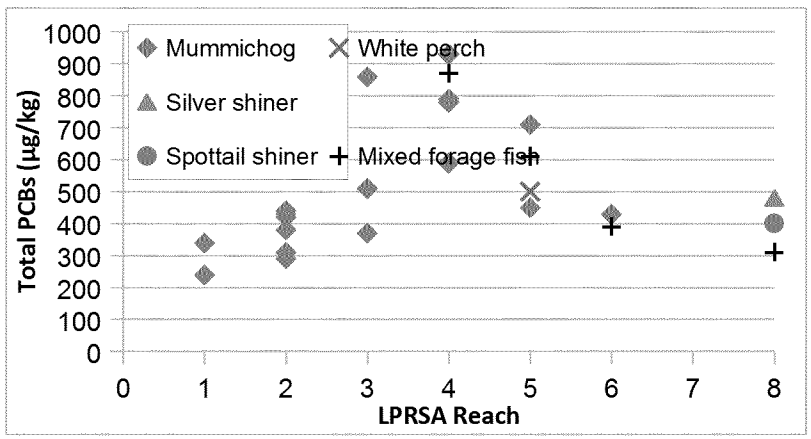
Note: Bars represent minimum and maximum values in composite sample.

Figure 4-6. Mean weight of small forage fish in analytical samples by LPRSA reach



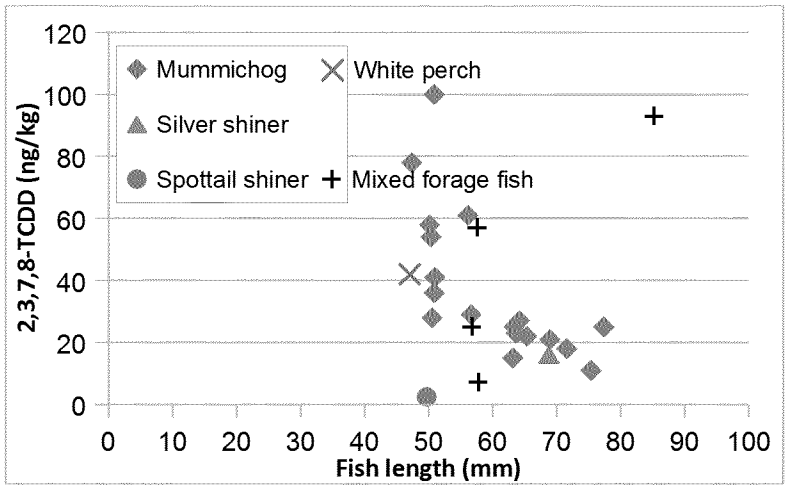
Note: Graph presents only small forage fish included in calibration dataset.

Figure 4-7. Small forage fish 2,3,7,8-TCDD concentrations by LPRSA reach



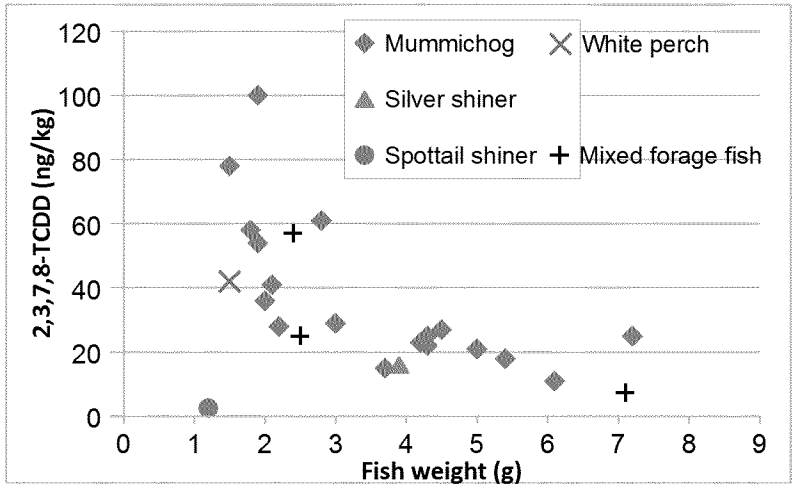
Note: Graph presents only small forage fish included in calibration dataset.

Figure 4-8. Small forage fish total PCB concentrations by LPRSA reach



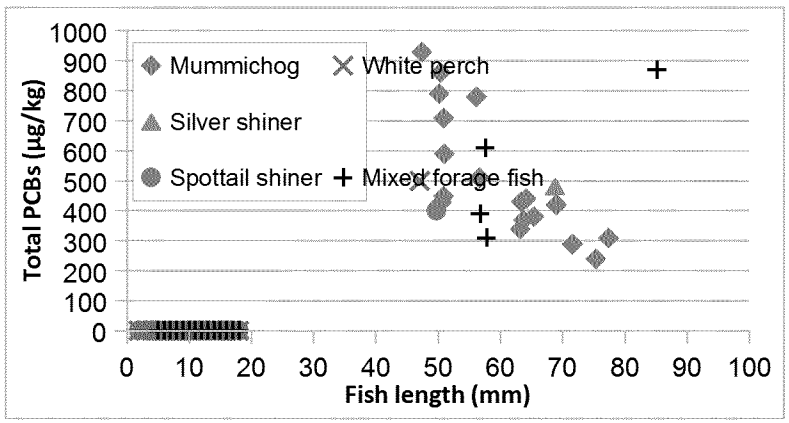
Note: Graph presents only small forage fish included in calibration dataset.

Figure 4-9. Small forage fish average composite length and 2,3,7,8-TCDD concentrations



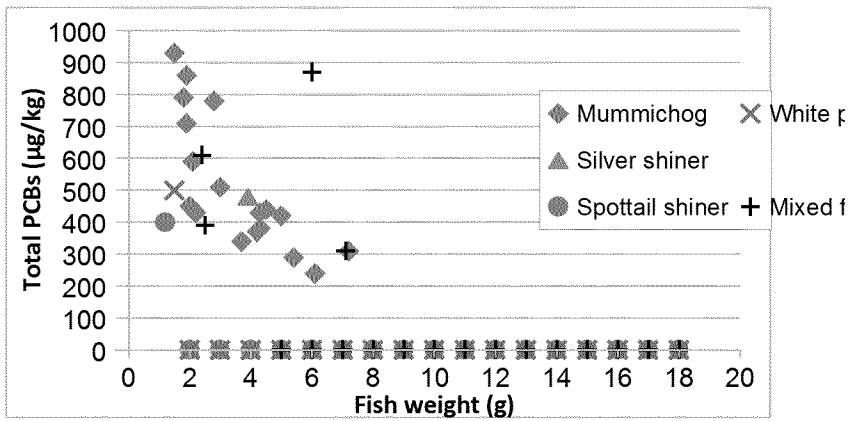
Note: Graph presents only small forage fish included in calibration dataset.

Figure 4-10.Small forage fish average composite weight and 2,3,7,8-TCDD concentrations



Note: Graph presents only small forage fish included in calibration dataset.

Figure 4-11. Small forage fish average composite length and total PCB concentrations



Note: Graph presents only small forage fish included in calibration dataset.

Figure 4-12. Small forage fish average composite weight and total PCB concentrations

4.3 OTHER FISH SPECIES

Whole-body tissue data from the LPRSA 2009 tissue collection effort (Windward [in prep]-b) were available for three additional fish species not explicitly modeled in the bioaccumulation model:

- Brown bullhead
- White sucker
- Northern pike

Whole-body data for these fish were based on the analysis of both fillet and carcass tissue from individual fish. Whole-body concentrations were mathematically reconstituted based on the fillet and carcass weights and concentrations. Figures 4-13 and 4-14 present data on the sizes of these other fish species. Figures 4-15 through 4-20 present concentrations of 2,3,7,8-TCDD and total PCB for these other fish species.

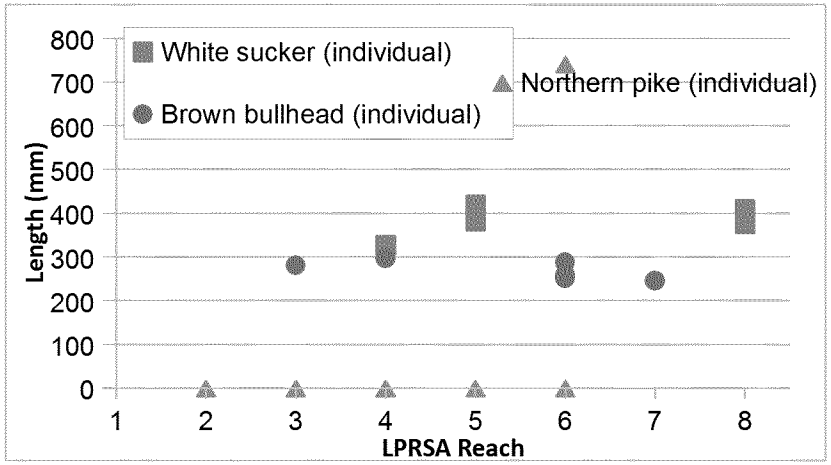


Figure 4-13. Length of other fish species in analytical samples by LPRSA reach

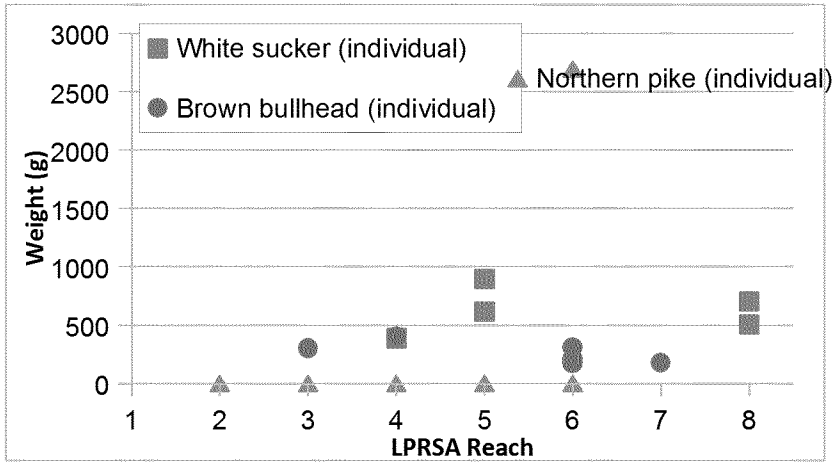


Figure 4-14. Weight of other fish species in analytical samples by LPRSA reach

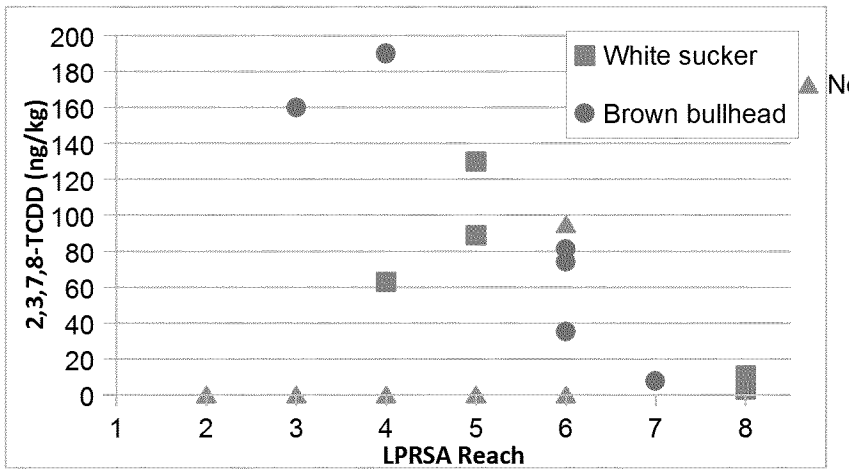


Figure 4-15. Other fish species whole-body 2,3,7,8-TCDD concentrations by LPRSA reach

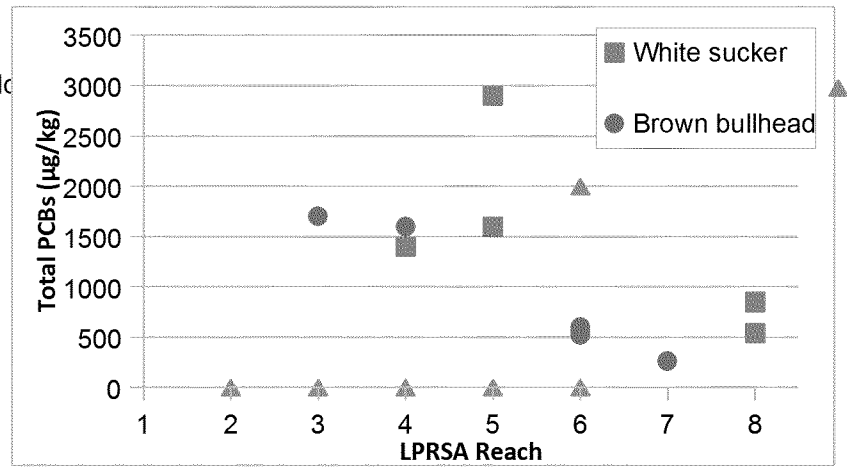


Figure 4-16. Other fish species whole-body total PCB concentrations by LPRSA reach

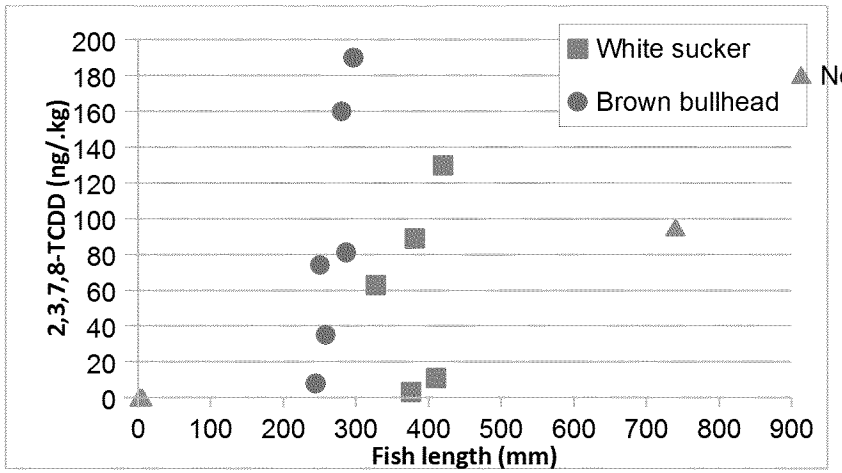


Figure 4-17. Other fish species length and whole-body 2,3,7,8-TCDD concentrations

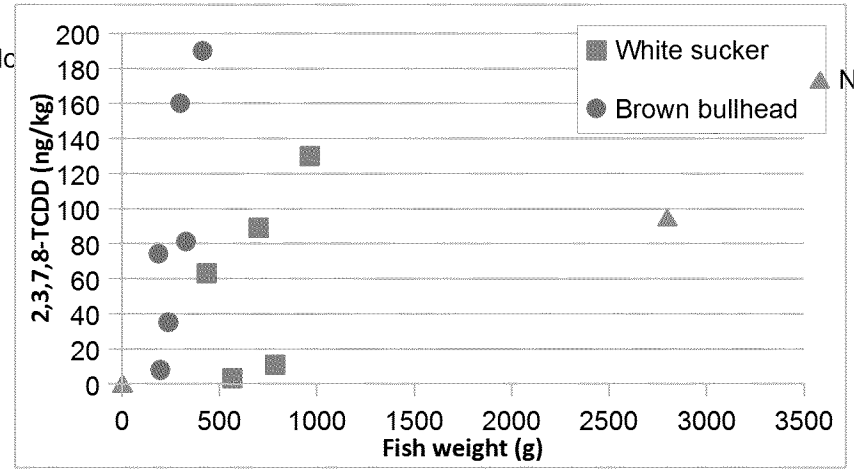


Figure 4-18. Other fish species weight and whole-body 2,3,7,8-TCDD concentrations

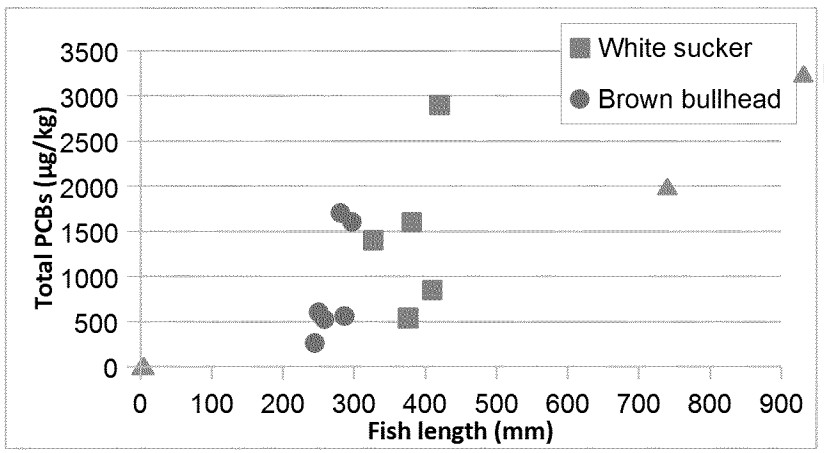


Figure 4-19. Other fish species length and whole-body total PCB concentrations

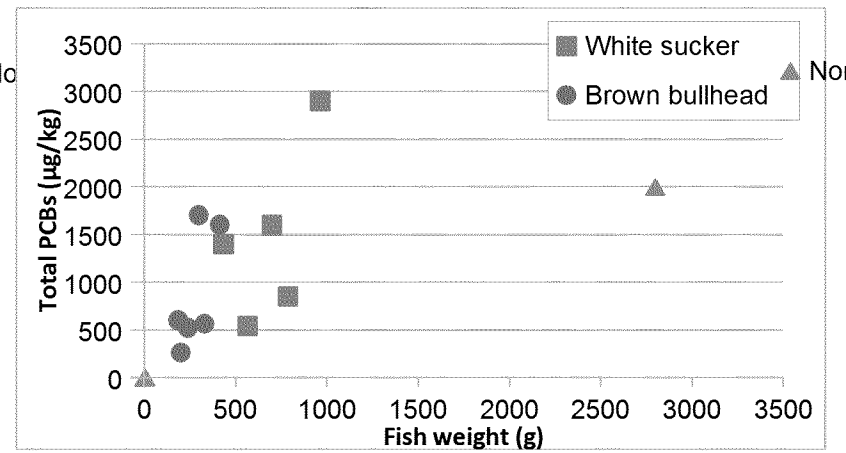


Figure 4-20. Other fish species weight and whole-body total PCB concentrations

4.4 BENTHIC INVERTEBRATE BIOACCUMULATION TISSUE

Benthic invertebrate tissue data from laboratory bioaccumulation tests based on LPRSA surface sediment collected in 2009 (Windward [in prep]-a) were available for:

- Estuarine worm (*Nereis virens)*
- Freshwater worm (*Lumbriculus variegatus*)

Composite bioaccumulation tissue data were evaluated as part of the uncertainty assessment (Section 4.2.1 of the main text) of the bioaccumulation model. Estuarine and freshwater worm data were compared with modeled benthic invertebrate carnivore/omnivore (C/O) and benthic invertebrate deposit feeder (DEP) compartments, respectively, based on the feeding habits of these species.[10] *L. variegates,* a head-down deposit feeder that can grow to be fairly large (generally as much as 9 mg wet weight [ww]) (Williams 2005; Vieira et al. 2006), was characterized as a DEP. *N. virens* was characterized as a C/O because it is a predatory carnivore; this estuarine worm can grow as large as 15 cm in length but is generally 1 to 5 cm long (Kristensen 1984; Caron and Desrosiers 2004). Figures 4-21 and 4-22 present bioaccumulation invertebrate 2,3,7,8-TCDD and total PCB concentrations.

[10] See Appendix E for details on benthic invertebrate compartment groups for the bioaccumulation model.

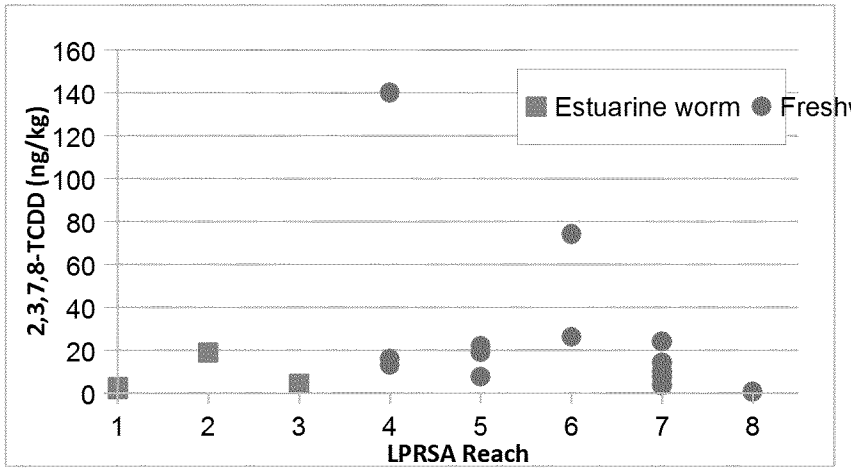


Figure 4-21. Benthic invertebrate bioaccumulation tissue 2,3,7,8-TCDD concentrations by LPRSA reach

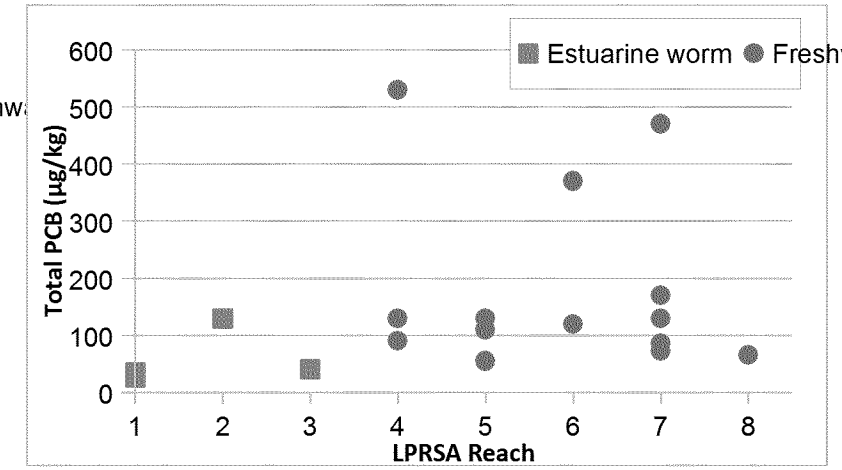


Figure 4-22. Benthic invertebrate bioaccumulation tissue total PCB concentrations by LPRSA reach

5 References

AECOM. [in prep]. Lower Passaic River Study Area creel/angler survey data report. Draft. March 2013. AECOM, Chelmsford, MA.

BBL. 2001. Summary of ecological sampling plan fish and blue crab community data. Blasland, Bouck & Lee, Inc.

California Fish Website. 2013. Channel catfish, *Ictalurus punctatus* [online]. Agreculture and Natural Resources, University of California, Davis, CA. [Cited 4/3/14.] Available from: http://calfish.ucdavis.edu/species/?ds=241&uid=19.

Caron A, Desrosiers G. 2004. Comparison of diet and feeding activity of two polychaetes, *Nephtys caeca* (Fabricius) and *Nereis virens* (Sars), in an estuarine intertidal environment in Quebec, Canada. J Exper Mar Biol Ecol 304:225-242.

George EL, Hadley WF. 1979. Food and habitat partitioning between rock bass (*Ambloplites rupestris*) and smallmouth bass (*Micropterus dolomieui*) young of the year. Trans Am Fish Soc 108:253-261.

Kristensen E. 1984. Life cycle, growth and production in estuarine populations of the polychaetes *Nereis virens* and N. *diversicolor*. Holarc Ecol 7:249-256.

NJDEP. 2001. Channel catfish (*Ictalurus punctatus*). Fish Fact Sheets [online]. Division of Fish & Wildlife, New Jersey Department of Environmental Protection, Trenton, NJ. [Cited 2/22/11.] Available from: http://www.state.nj.us/dep/fgw/pdf/fishfact/chanlcat.pdf.

Rogers SG, van den Avyle MJ. 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (mid-Atlantic): Atlantic menhaden. Biological Report 82 (11.108). Coastal Ecology Group, US Army Corps of Engineers, Vicksburg, MS and National Wetlands Research Center, US Fish and Wildlife Service, Slidell, LA.

Turner JL. 1966a. Distribution and food habits of centrarchid fishes in the Sacramento-San Joaquin delta. In: Turner JL, Kelly DW, eds, Fish Bulletin 136. California Department of Fish and Game, Sacramento, CA, pp 144-153.

Turner JL. 1966b. Distribution and food habits of ictalurid fishes in the Sacramento-San Joaquin delta. In: Turner JL, Kelly DW, eds, Fish Bulletin 136. California Department of Fish and Game, Sacramento, CA, pp 130-143.

Vaughn S. 2010. Personal communication (e-mail to R. Law, de maximis, regarding tissue sampling and compositing meeting). US Environmental Protection Agency. January 8, 2010.

Vieira NKM, Poff NL, Carlisle DM, Moulton SR, Koski ML, Kondratieff BC. 2006. A database of lotic invertebrate traits for North America. Data series 187. US Geological Survey, Reston, VA.

Wellborn TL. 1988. Channel catfish life history and biology. Publ. no. 180. Southern Regional Agriculture Center, Texas Agricultural Extension Service, College Station, TX.

Williams PM. 2005. Feeding behaviour of *Lumbriculus variegatus* as an ecological indicator of *in situ* sediment contamination. Doctor of Philosophy, University of Stirling, Stirling, Scotland. 256 pp.

Windward. 2009a. Memorandum dated November 6, 2009, to Robert Law, de maximis, inc.: Proposed sample analysis plan for fish/decapod tissue for the Lower Passaic River Restoration Project. Windward Environmental LLC, Seattle, WA.

Windward. 2009b. Quality Assurance Project Plan: Fish and decapod crustacean tissue collection for chemical analysis and fish community survey. Final. Prepared for Cooperating Parties Group, Newark, NJ. August 6, 2009. Lower Passaic River Restoration Project. Lower Passaic River Study Area RI/FS. Windward Environmental LLC, Seattle, WA.

Windward. 2010a. Fish and decapod field report for the late summer/early fall 2009 field effort. Final. Prepared for the Cooperating Parties Group, Newark, NJ. September 14, 2010. Lower Passaic River Restoration Project. Windward Environmental LLC, Seattle, WA.

Windward. 2010b. Memorandum dated February 8, 2010, to Robert Law, de maximis, inc.: Revised sample analysis plan for blue crab tissue for the Lower Passaic River Restoration Project. Windward Environmental LLC, Seattle, WA.

Windward. 2010c. Memorandum dated June 14, 2010, to Stephanie Vaughn, USEPA: Revised white perch analysis plan for the Lower Passaic River Restoration Project. Windward Environmental LLC, Seattle, WA.

Windward. 2010d. Memorandum dated June 18, 2010, to Stephanie Vaughn, USEPA: Revised American eel analysis plan for the Lower Passaic River Restoration Project. Windward Environmental LLC, Seattle, WA.

Windward. 2010e. Memorandum dated May 21, 2010, to Robert Law, de maximis, inc.: Revised sample analysis plan for catfish/bullhead, carp, bass white sucker, and northern pike tissue for the Lower Passaic River Restoration Project (revised fish sample analysis plan, part 1). Windward Environmental LLC, Seattle, WA.

Windward. 2010f. Revised analysis plan for the small forage fish tissue samples. Memorandum dated November 1, 2010, to Cooperating Parties Group. Lower Passaic River Restoration Project. Lower Passaic River Study Area RI/FS. Windward Environmental LLC, Seattle, WA.

Windward. 2011. Fish community survey and tissue collection data report for the Lower Passaic River Study Area 2010 field efforts. Final. Prepared for Cooperating Parties Group, Newark, NJ. July 20, 2011. Lower Passaic River Restoration Project. Lower Passaic River Study Area RI/FS. Windward Environmental LLC, Seattle, WA.

Windward. [in prep]-a. 2009 bioaccumulation tissue chemistry data for the Lower Passaic River Study Area. Draft. Prepared for Cooperating Parties Group, Newark, NJ. Submitted to USEPA September 19, 2011. Lower Passaic River Restoration Project. Lower Passaic River Study Area RI/FS. Windward Environmental LLC, Seattle, WA.

Windward. [in prep]-b. 2009 fish and blue crab tissue chemistry data for the Lower Passaic River Study Area. Draft. Prepared for Cooperating Parties Group, Newark, NJ. Submitted to USEPA September 19, 2011. Lower Passaic River Restoration Project. Lower Passaic River Study Area RI/FS. Windward Environmental LLC, Seattle, WA.

Windward. [in prep]-c. 2010 small forage fish tissue chemistry data for the Lower Passaic River Study Area. Draft. Prepared for Cooperating Parties Group, Newark, NJ. Submitted to USEPA July 18, 2012. Lower Passaic River Restoration Project. Lower Passaic River Study Area RI/FS. Windward Environmental LLC, Seattle, WA.

Wydoski RS, Whitney RR. 1979. Inland fishes of Washington. University of Washington Press, Seattle, WA.